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Reducing Neonatal Intensive Care Transports by Introducing a Regional Nurse Flex Pool

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MANAGEMENT SUMMARY

Research goal and context

On a yearly basis, approximately 4100 newborns are in need of neonatal intensive care, which is the care associated with sick or prematurely born babies, starting from 24 weeks. These patients may experience complications due to their low gestational age, weight, and developmental phase. When the newborn requires intensive care and monitoring, they are referred to one of the nine neonatal intensive care units (NICU) in the Netherlands.

Neonatal care in the Netherlands is organised in regions and each NICU is responsible for its own catchment area. This means that every patient is assigned a primary NICU. If a location is fully occupied, it may be forced to reject a patient from their own catchment area. The patient then has to be transported to another NICU, preferably antenatally but occasionally postnatally. This means that the patient has to be treated further away from home and cannot be treated by its own doctor. Neonatologists across the Netherlands have expressed the need to decrease the number of patient transfers.

The capacity constraints surrounding the NICUs mainly revolve around nursing capacity rather than bed capacity. To decrease the number of patient transports, previous research has focused on reallocating general hospitals to NICUs (Buter, 2019) and the pooling effects that can be achieved within a NICU location (Weernink, 2018) (Otten, 2017). So far, however, there has been little debate about solutions for making more efficient use of nursing capacity between NICUs. Given the modest distances between the NICUs in the Netherlands, the idea arose to assess the effects of implementing a flex pool of nurses that allows for the movement of nurses between the locations instead of patients.

Methods

We consider the flex pool of nurses to consist of nurses who are willing and capable to work at multiple locations. Every nurse in the pool is employed by one NICU and if the nurse is not required elsewhere, the nurse works at the primary workplace. The nurses in the flex pool are informed before the start of the shift where they are expected to work. A nurse is not required to work at multiple NICU locations in one shift as this would not result in the most efficient use of the nurses' working time.

We are the first to analyse if and to what extent the implementation of a flex pool of nurses can reduce the number of patient transports in the Dutch neonatal network. For this purpose, we have created a discrete event simulation. An integer linear problem is incorporated in the model to optimally allocate incoming patients and flex nurses to NICU locations. The main objective of the integer linear problem is to minimise travel distance for patients and nurses. The model allows for experimentation with different flex pool configurations and various exchange strategies. In this research, the model is used for a case study on the Dutch neonatal network, but the model can easily be adapted to other (health care) networks. The data used for the parameter estimation comes from three main sources: the capacity data tool for BabyZoektBed, Perined, and Wilhelmina Children's hospital.

The configurations used in the experiments to analyse the performance of the flex nurse pool focus on varying the number of participating nurses, the number of NICU locations, and the cross-training policies. The settings for the number of participating locations include all nine NICU locations, all locations except for Groningen and Maastricht, and only including the more centrally located/randstad locations. The experiments analyse three cross-training policies: n-to-all, reciprocal pairs, and chaining. In the n-to-all policy, all included locations can exchange nurses. In the reciprocal pairs policy the NICUs form pairs between which they can exchange nurses. In the chaining policy, the NICUs form a chain and each NICU can accept nurses from one other location and can send nurses to one other location.

Results

Figure 1 presents the results of the two most promising configurations and shows that the implementation of flex nurses significantly decreases the number of patient transports, even when only a limited number of nurses participate in the pool or when only a limited number of locations participate in the pool.

The most promising results in terms of patient transport reduction occur when five nurses participate in the pool, when all locations are involved in the system, and when the n-to-all cross-training policy is chosen. The results show that when these configurations are used, the percentage of transported patients can be reduced by approximately 70%. This means that on a yearly basis on average 260 patients have to be transported compared to the approximately 870 patients that have to be transported when the flex pool is not used.

However, when taking into account the ease with which nurses can participate in the flex pool, this is not considered the best option. The configuration where two nurses participate per location, where all locations are included except Groningen and Maastricht, and where the reciprocal pairs policy is used limits the number of locations nurses have to be familiar with. This configuration still reduces the required patient transport with approximately 35%, which means on average 560 patients are transported in a year compared to the 870 in the baseline measurement.

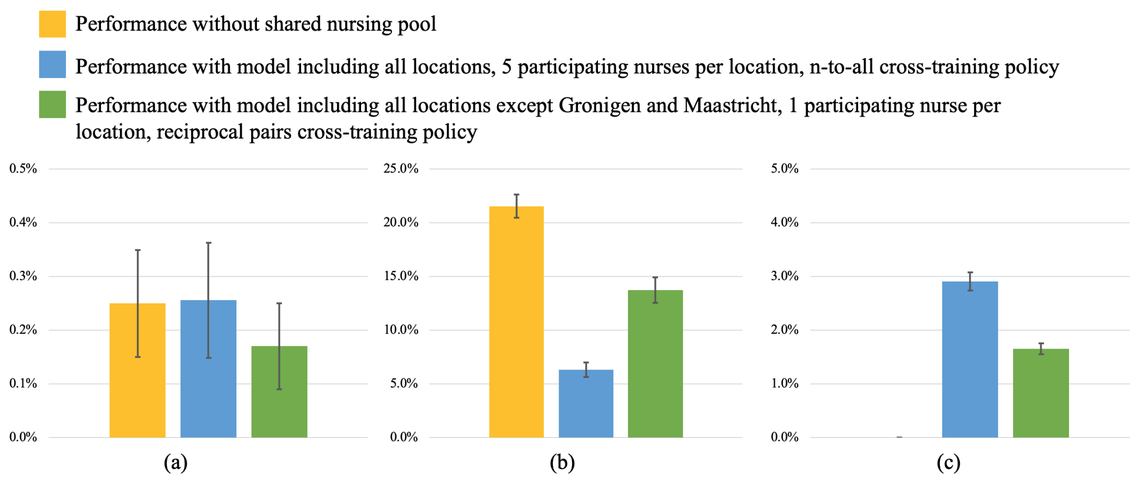

Figure 1: Performance of the model without flex pool (in yellow) and two best performing configurations (in blue and green), where a) represents the number of rejected (transported abroad) patients as a percentage of the total incoming patients, b) presents the number of transported patients as a percentage of the total number of incoming patients, and c) presents the number of shifts in which a flex nurse is transferred to a NICU location other than their primary work location. Error bars indicate the 95% confidence interval of the mean.

Conclusion and discussion

The analysis shows that a flex nursing pool contributes to reducing patient transport. When implementing such a system in real-life, we recommend to start with a limited number of nurses in the pool and to train these nurses using the reciprocal pairs policy. Furthermore, we recommend to start with a limited number of participating locations, preferably those who are centrally located in the Netherlands. Once this has been successfully implemented, the pool can be extended to include more nurses and more NICU locations.

It is important to bear in mind the possible biases in these results. Improving the quality of the data used for the estimation of input parameters can increase the reliability of the results. However, the sensitivity analysis shows that if the number of patients or the length of stay of patients are increased by 10%, the flex pool of nurses still results in significantly less patient transport. For the configuration with five participating nurses, inclusion of all locations, and the n-to-all policy this results in an approximate reduction of 60% compared to the previous 70%. For the configuration with two participating nurses, inclusion of all locations except Groningen and Maastricht, and the reciprocal pairs policy this results in a reduction of approximately 25% compared to the previous 35%.

Furthermore, in real-life, NICU locations often make use of emergency beds to place patients from their own catchment area, which are not incorporated in the simulation model. Using these beds is not preferred and not a long-term solution, as this results in lower nurse-to-patient ratios and increases the workload for nurses. In the model, this may have caused the number of patient transports to be higher than experienced in practice. For this reason, the model has been validated by neonatologists from three different NICU locations, who concluded that the model sufficiently represents the Dutch neonatal network to examine the flex pool with.

Finally, we realise that there are practical thresholds to implementing a flex pool of nurses, but we think that with the current NICU nurse capacity, there is a need for outside the box solutions. The results of the research provide quantitative data on the improvement potential of introducing a flex pool of nurses in the Dutch neonatal network. Neonatologists in the Netherlands have been trying for years to decrease the number of patient transports and this research provides a quantitative basis to support the discussion on whether a flex pool of nurses should be implemented.

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Kimberley Morris

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CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	**Definition**
BZB	Baby zoekt bed
CI	Confidence interval
CVRP	Capacitated vehicle routing problem
DES	Discrete event simulation
EVV	Eerste verantwoordelijke verpleegkundige (first responsible nurse)
HC	High care
ILP	Integer linear problem
KPI	Key performance indicator
LOS	Length of stay
MC	Medium care
NIC	Neonatal intensive care
NICU	Neonatal intensive care unit
NVK	Nederlandse Vereniging voor Kindergeneeskunde
UMC	University medical center
WKZ	Wilhelmina Kinderziekenhuis

1 INTRODUCTION

The research presented in this paper aims to demonstrate the improvement potential of implementing a flex pool of nurses in the Dutch neonatal network. In doing so, it intends to determine the extent to which patient transfers can be reduced and the number of times nurse exchanges take place.

This chapter introduces the problem context and the research goals. Section 1.1 establishes the context of the research, sets out the problems experienced in the Dutch neonatal network, and selects the core problem. Section 1.2 identifies the goal of the research and determines the research questions and methods.

1.1 Problem definition

1.1.1 Context description

In the Netherlands, uncomplicated births can take place at home, in birth centers, or at hospitals. However, if medical complications do occur concerning the pregnancy or the delivery, the patient is advised to deliver the baby in a general hospital. In case the complications surrounding the pregnancy or the newborn's health become too severe for treatment at a general hospital, the patient is referred to a perinatal center. These centers are specialised in providing care for highly complex cases surrounding gynaecology and pediatrics.

When the newborn requires intensive care and monitoring, they are treated at a neonatal intensive care unit (NICU). Neonatal care is the care associated with sick or prematurely born babies, starting from 24 weeks. These patients may experience complications due to their low gestational age, weight, and developmental phase (Adeyemi et al., 2011). In addition, the NICU also treats newborns suffering from, amongst others, infections, birth defects, or complex diagnostics.

Neonatal care is an expensive type of care due to its complexity. For this reason, a trade-off has to be made between the costs of neonatal care and the accessibility of it. To elaborate, creating one NICU location will result in long travel times for most patients, but creating a NICU in every hospital will result in high costs. Therefore, in the Netherlands the decision has been made to create nine NICU locations. Together, the NICU locations make up the Dutch neonatal network. The locations are spread across the country to ensure that patients have reasonable accessibility to neonatal care.

All general hospitals in the Netherlands are affiliated with one of the nine NICU locations, their so-called "primary NICU". When a general hospital has admitted a patient that needs neonatal care, they refer the patient to their primary NICU. Usually, this is the location that is closest to the general hospital as this limits travel times for patients. The general hospitals that share the same primary NICU comprise its catchment area. A NICU is responsible for ensuring a bed for all patients in their catchment area. However, it may occur that the NICU itself does not have any beds available. When this happens, the NICU must contact other locations and relocate the patient to a NICU with an available bed. When looking for an alternative location, neonatologists try to place the patient as close to their family as possible.

1.1.2 Problem definition

In recent years, the Dutch neonatal network has been under pressure. NICU locations often experience that they have to reject patients from their catchment area due to an inability to admit the patient. When there are signs that an unborn child requires neonatal care, the primary NICU together with the parents try to prepare for the birth as much as possible. If the NICU is fully occupied at the time of birth, the medical professionals try to relocate the mother to the available NICU before the child is born, so antenatally. If this is not possible, the patient is transported postnatally.

Transporting patients, even if they are still unborn, has negative consequences. First, neonatologists have to spend time and effort to find another NICU location with enough available capacity to admit an additional patient. Even though efforts have been made to make this process more efficient, it still takes time of neonatologists away from the patients that are admitted to the NICU (Nederlandse Vereniging voor Kindergeneeskunde, 2019). Moreover, transporting a patient to a location further away from their family negatively impacts a patients' recovery (NOS, 2019). Also, transporting the patient poses the risk of losing information during the transfer between the two NICUs. For these reasons, it is important that patient transfers between NICU locations ought to be minimised.

Previous research regarding the capacity planning of (one of the locations in) the Dutch Neonatal Network has focused on how to more efficiently manage the demand of care in order to reduce travelling time of patients. For example, Buter (2019) focused on minimising the Neonatal Intensive Care travel and transport time. In addition, Weernink (2018) and Otten (2017) investigated the effect of pooling intensive care and high care units within a neonatal department. Even though these projects have provided valuable recommendations for decreasing patient transport and increasing NICU capacity, the problem is still present at NICU locations.

For this reason, it is important to investigate other causes and solutions for decreasing patient transport. In our problem analysis we have identified several core problems that contribute to the number of patient transports and are yet to be solved. These problems are as follows:

1. Currently, NICU locations have difficulty utilising all their physical beds. For example, Wilhelmina Children's Hospital (WKZ) houses 24 physical NICU beds, but the NICU location is rarely able to utilise more than twenty beds. The reason NICUs cannot open all their physical beds is because there are insufficient nurses to provide an adequate quality of care for patients if the nursing capacity has to be spread across all 24 beds.

2. Patients admitted to the NICU cannot be timely admitted to downstream resources, such as high care (HC) or medium care (MC) units. This causes patients to occupy a NICU bed longer than medically required and subsequently disables new patients to be admitted to the ward. At the moment, patients at times cannot be transferred to HC or MC units is because of a shortage of nursing capacity at these facilities.

3. There is no forecast model for national or regional demand of neonatal care. This prevents NICU locations to adapt their operational capacity to the demand of neonatal care. As the demand for neonatal care is volatile, NICUs to have to reject patients in busy periods. Part of the demand for neonatal care might be predictable, but limited efforts have yet been made to create a model for this.

4. The capacity of NICU locations is not determined based on the demand of the NICU's catchment area. The assignment of general hospitals to their primary NICU is based on historical assignment, but does not take into account the current capacity of the NICU locations. This may cause a discrepancy between the demand of care in a catchment area and the supply of care in a catchment area.

Ideally, all core problems should be solved. However, due to time constraints not all core problems can be solved in this project. The overlapping theme in the core problems is the capacity constraints for the NICUs, which mainly revolves around nursing capacity rather than bed capacity. Unfortunately, it is very costly to increase NICU capacity and it takes years to train new nurses. However, we can try to use the current nursing workforce more efficiently. Pooling the nursing workforce of different NICU locations could result in the ability to treat more patients with the same number of nurses. Given the modest distances between the NICU locations in the Netherlands, the idea arose to not move patients between NICUs but instead share nurses between the locations by creating a flex pool of nurses. In this way, the number of patient transfers can be reduced without increasing the number of NICU nurses. By moving nursing capacity between NICU locations according to patient demand, we can contribute to solving all core problems mentioned above.

1.2 Research design

1.2.1 Research aim and objectives

The aim of this study is to assess the benefits of creating a flex pool of nurses in the Dutch neonatal network. In doing so, we aim to demonstrate the improvement potential of such a system by looking at the possible reduction in the number of patient transports. The results are meant to function as a quantitative basis to provide objective support for the discussion between the heads of neonatal departments in the Netherlands on whether such a system should be implemented.

The research objectives to support this aim include constructing a model that allows us to analyse the effects of implementing a flex pool of nurses. For this, we will identify relevant experimental factors and performance indicators. This will lead to a recommendation for improvement when using this system in the Dutch neonatal network.

The research is performed in close collaboration with Wilhelmina Children's Hospital (WKZ). This collaboration enables us to make accurate assumptions about the implementation of a flex pool of nurses based on medical practice. WKZ in turn, gains insight into the capacity related issues faced by the NICU network. Furthermore, data from BabyZoektBed, the capacity dashboard tool for Dutch NICUs, is used for the analysis on the number of operational and available beds at NICU locations in the Netherlands.

1.2.2 Research questions and methods

To achieve the aim set out for this research, the following main research question is posed: *"To what extent can patient transfers be reduced by creating a flex nursing pool between NICUs?"*

This question can be answered by means of different methods. An analytical queuing model can be created that models the Dutch neonatal network as individual queues for each NICU location. However, apart from being time consuming and rather complex, the risk of creating an analytical model is that many assumptions and simplifications have to be made, which may mean that the model will deviate from reality. Another option is to create a simulation model, which allows us to reflect the Dutch neonatal network more accurately. Even though this would result in a heuristic approach and not an exact approach, it does allow for evaluation of the flex pool of nurses.

Several sub-questions are formulated that allow us to answer the main research question in a structured and systematic way. The first three sub-questions are focused on identifying and understanding the environment and theory that are relevant for the research. The last two questions concern the methods used to model and evaluate the intervention proposed in this research. Together, these questions form the answer to the main research question.

1. **How is neonatal care currently organised in the Netherlands?**
   To attain the goal of the research, it is important to gain an understanding of how neonatal care is organised in the Netherlands. Therefore, Chapter 2 elaborates on the organisational structure of NICUs and the patient care pathways of neonates. Furthermore, the chapter presents a data analysis of the current operational and available beds at NICUs. The question is answered by means of expert opinions and data analysis.

2. **What methods are commonly used to solve or manage capacity constraints resulting from nursing capacity and which of these methods is most appropriate for the Dutch neonatal network?**
   To answer this question, a literature review is performed. The results of this literature review are presented in Section 3.1. The database used for the literature review is the Scopus database, in which articles were selected based on relevant search terms identified in the title, keywords, and abstract of search results. The goal of the literature review is to present an overview of the relevant literature and to select an appropriate method for solving the nursing capacity constraints at NICU locations.

3. **What are the organisational implications of the chosen staffing shortage solution?**
   A second literature review is performed to answer this research question. Based on the answer to the first research question, new search terms are formulated. Again, the Scopus database is used and the relevant articles are identified by reviewing the title, keywords, and abstract based on the identified search terms. The question is answered in Section 3.2.

4. **How can we model the Dutch neonatal network and the flex pool of nurses?**
   This question is answered in Chapter 4 and presents the assumptions and inputs used for the simulation model. The chapter aims to explain the simulation approach used and the experimental design created for testing the flex pool of nurses. To answer this question, the conclusions from questions 2 and 3 are used as input as well as expert opinions.

5. **What are the effects of different policies concerning the flex pool of nurses on the number of patient transfers and the number of nurse exchanges?**
   Chapter 5 presents and analyses the results from the simulation model created in the previous chapter. The effects of different policies concerning the flex pool of nurses are discussed. Also, a sensitivity analysis of several input parameters of the most promising configurations is presented to assess the robustness of the outcomes.

After answering the sub-questions, the main research question will be answered in Chapter 6. Furthermore, recommendations will be made about the most effective policies regarding the organisation of a flex pool of nurses. The chapter also discusses the theoretical contributions and practical contributions of the research. Moreover, the limitations of the research are presented and ideas for further research are shared.

1.2.3 Research scope

The research aims to evaluate patient transport resulting from an inability of the primary NICU to admit a patient. This is why patient transport between general hospitals, regional hospitals, and birth centers are considered out of scope. The reason is that patients have to relocate from these institutions regardless of whether or not they can be treated at their primary NICU. It would thus add unnecessary complexity to the model to include any other health facilities other than the NICUs.

Following the same reasoning, the scope of this research is limited to the neonatal intensive care provided in the Netherlands. This means that the nine NICU locations in the Netherlands are included, but that the high care and medium care wards are excluded. Any NICU locations outside the Netherlands are also excluded from the analyses en models presented in this report.

There are many barriers that would complicate the implementation of this system. These barriers include, but are not limited to, legal, organisational, and financial barriers. However, the results of the research are meant to provide information on the quantitative effects of implementing a flex pool of nurses in the Dutch neonatal network. Therefore, the effects and implications of these barriers are considered out of scope.

2 BACKGROUND INFORMATION

The goal of this chapter is to answer the first research question; *"How is neonatal care currently organised in the Netherlands?"*. To attain this, the research context is presented including relevant stakeholders, processes, and data. First, we will explain the different health institutions included in the system in Section 2.1. Then, Section 2.2 explains the care pathway of patients. Finally, Section 2.3 presents a data analysis on the number of operational and available beds in the year 2020.

2.1 Dutch Neonatal Network

2.1.1 Regional hospitals, birth centers, and neonatal intensive care units

The Dutch health sector allows women to choose where they want to give birth. When a woman has a low-risk pregnancy, she can choose to give birth at home, in a birthing center or in a regional hospital (Boesveld et al., 2017). In case there are risks associated with the pregnancy, the birth or if postpartum care is required, the woman is referred to a secondary care facility (Hermus et al., 2015). These secondary care facilities consist of general hospitals, of which there are 74 in the Netherlands. When the level of care required for a complicated birth becomes too high for a general hospital, they have to refer the patient to a hospital that provides more specialised care, the NICU. This is why all general hospitals are affiliated with one specific NICU location, their so-called primary NICU. Together, all hospitals that share the same primary NICU comprise its catchment area.

Due to the scope of the research, we will not elaborate further on the locations or demand of the general hospitals. Since this research aims to investigate the number of patient transfers between different NICU locations, it will suffice to express the demand in terms of the number of patients that occur at NICU locations. So, we will only consider the aggregated general hospital demand, which is expressed by the patient demand at a NICU location.

In the Netherlands there are ten NICU locations. However, the locations VUmc and AMC in Amsterdam are merging, which is why we will consider them as one Amsterdam location and thus in total we consider nine locations. Of these locations, seven are located in UMCs. In order to provide more accessibility to neonatal care, it was historically decided to create two additional locations. These departments are located in Máxima MC in Veldhoven and Isala hospital in Zwolle. Figure 2.1 shows the graphical dispersion of all NICU locations and shows why these two locations are strategically chosen for the accessibility to neonatal care.

Figure 2.1: NICU locations in the Netherlands - All NICU departments are located in UMCs except for Isala hospital in Zwolle and Máxima MC in Veldhoven. These locations have been added to the Dutch neonatal network to provide more accessibility to neonatal care.

2.1.2 Demand for neonatal care

The number of NICU admissions can be calculated by multiplying the total number of births by the percentage of births that result in a NICU admission. Table 2.1, column "Total births", shows the total number of births in the Netherlands in the years 2015-2019 (Nederlands Jeugdinstituut, 2021). The column "NICU admissions (%)" shows the number of NICU admissions as a percentage of the total number of births in the Netherlands for the same period (Perined, 2021). The column "NICU admissions (# patients)" shows the estimated number of NICU admissions of the respective years, calculated by multiplying the number of births by the percentage of NICU admissions. The data shows that the average number of NICU admissions in the Netherlands over the period 2015-2019 is equal to 4057.

Table 2.1: Data on NICU demand in the years 2015-2019, sources: Nederlands Jeugdinstituut (2021) and Perined (2021)

Year	**Total births**	**NICU admissions (%)**	**NICU admissions (# patients)**
2015	170,510	2.33	4072
2016	172,520	2.26	4061
2017	169,836	2.52	4280
2018	168,525	2.41	3899
2019	169,680	2.40	3973

Table 2.2 shows the percentage of births for each region in the Netherlands (Perined, 2018). The chance of a pregnancy resulting in a NICU admission does not depend on the region where the mother lives. Therefore, the percentages presented in Table 2.2 is representative for the regional NICU demand in the Netherlands. By multiplying the average number of NICU admissions in the years 2015-2019 in the Netherlands by the percentage of demand for a region, we estimate the yearly NICU demand for every region, which is shown in the column "NICU demand per region".

Table 2.2: Average NICU demand per region in the years 2015-2019, source: Perined (2018)

Region	**Percentage of NICU demand per region**	**NICU admissions per region**
Amsterdam	20.4	828
Groningen	9.5	385
Leiden	9.2	373
Maastricht	4.8	195
Nijmegen	8.8	357
Rotterdam	18.1	734
Utrecht	13.7	556
Veldhoven	7.7	312
Zwolle	7.7	312

2.1.3 Specialised treatment

Within neonatal care, there are several specialised treatments that not every location is able to provide for patients. These treatment types include pediatric surgery (PS), pediatric neurosurgery (PNS), pediatric cardiac surgery (PCS), and extra corporeal membrane oxygenation (ECMO). Table 2.3 shows which NICU locations are able to provide the types of specialised treatments. If a patient from a certain catchment area requires a treatment type that is not provided at their primary NICU, they must be relocated to a NICU that does provide this treatment. So, irrespective of whether the primary NICU has the capacity to admit an additional patient, the patient must be transported to another NICU. This means that this type of transportation cannot be avoided.

As mentioned, this research aims to analyse how a flex pool of nurses can decrease the number of patient transports. In the situation where a patient requires care that is not provided at their primary NICU, their transport is unavoidable and the flex pool will not be able to reduce this type of transport. The percentages of patients that require these specialised treatments are not easily accessible. For this reason, combined with the fact that this transport cannot be avoided, we have chosen not to consider these treatment types in our research.

Table 2.3: Availability of specialised treatments at NICU locations, source: Buter (2019)

Location	**PS**	**PNS**	**PCS**	**ECMO**
Amsterdam	X	X		
Groningen	X	X	X	
Leiden		X	X	
Maastricht	X	X		
Nijmegen	X	X		X
Rotterdam	X	X	X	X
Utrecht	X	X	X	
Veldhoven				
Zwolle				

2.1.4 Personnel types

The staff at neonatal departments mainly consists of neonatologists, physician assistants, residents, nurses, support staff, and students. All these types of personnel contribute to providing a high quality of care and service at a NICU location. For this reason, a shortage in capacity for all these types is problematic. However, some shortages are more problematic than others.

A shortage in support staff, for example, would only jeopardise the quality of care or service if this is a structural issue. There are days on which support team might be understaffed, but on these days the neonatal department can still function and provide care for neonates. On the contrary, when there is a shortage in neonatologists or nurses, the department is not able to guarantee a safe patient-to-doctor or patient-to-nurse ratio. Luckily, there is no shortage of neonatologists in the Netherlands, which means that this does not pose a risk for the quality of care or service. Unfortunately, as mentioned before, there is a shortage in nursing capacity. Without enough nurses on the wards, NICU units are not able to provide the quality of care that is necessary and therefore capacity is scaled back.

To be qualified to work on a NICU, nurses have to follow a specialisation within their education. During this study, the students have to complete an internship at NICU locations. As an intern, they are placed under supervision of a nurse and in this way are able to gain relevant experience. Even though these students contribute to the care provided, they are not counted in the nursing capacity as they require constant supervision of NICU nurses. Once a person has finished the NICU nurse education, he or she is eligible to independently work with patients.

2.1.5 Nurse scheduling at the Wilhelmina Kinderziekenhuis

The organisation of nurses at NICU locations may differ, but to give an impression we will discuss the way manner in which nurses are organised at WKZ. The NICU at WKZ is divided in three different units, each of which has eight beds. For each unit, three nurses are scheduled to provide care for the patients on this unit. The most experienced nurses of these three, the so-called "eerste verantwoordelijke verpleegkundige" (EVV) or "first responsible nurse", carries the responsibility for care at this unit. A nurse may be eligible for being an EVV, after gaining a year of experience as a NICU nurse. Since nurses can fulfill the role of EVV after a year of experience, there is no shortage in specifically EVV capacity.

WKZ schedules, on average, one nurses per two patients. This means that the patient-to-nurse ratio at this location is 1:2 on average. This ratio however, is dependent upon the acuity of the patient placed in the unit. At times, it happens that patients require the full-time care of a nurse. In this case, the nurses may be fully occupied even though not all beds are filled. So, the patient-to-nurse ratio will then be lower than on average.

At WKZ, patients are assigned a fixed nurse where possible. Since a nurse cannot work all the time, this results in a patient having approximately three nurses that care for them. This type of care and scheduling allows familiarity between the nurses and the patient and parents. Furthermore, it also ensures that the nurses notice more quickly whether the health of the patient is improving or degrading.

2.2 Patient care pathway

2.2.1 Patient arrival

There are different ways in which a patient can arrive at a NICU location. The first way is that a patient can be born in the same hospital as the NICU is located in. Another way is that the patient can be referred to the NICU location by a regional birth center or hospital in the catchment area of the NICU. Finally, the patient can also be referred to the NICU location from a catchment area that is different than that from the NICU location.

When a patient presents itself to a NICU location, the coordinating doctor and coordinating nurse have to make a judgement call on whether or not the patient can be admitted to the NICU. This assessment is made based on the nurses and doctors available, the cumulative acuity of the already admitted patients, and whether or not there is a bed available. Only when all factors allow the admission of an additional patient, can the patient be admitted to the NICU.

An important estimation in this decision is the acuity of the patient that has to be scheduled. When creating the schedule, the planners assume a patient acuity that requires the care of half a nurse. This ratio is supported by literature, where nurse-to-patient ratios at critical care units also equals one nurse for every two patients (Ann, 2001). The research of Hoek (2015), presents a more detailed estimation of patient acuity levels at specifically the NICU at WKZ. The paper also presents the probability of a patient with a certain acuity level and allocates a nurse-to-patient ratio to each acuity level. The distribution of the different care levels and their accompanying required nurse-to-patient ratio is shown in Table 2.4. So, the table can be read in, for example, the following way: 39% of the incoming patients have an acuity that requires 0.33 nurse. A nurse could thus handle at most three patients with this acuity. The average acuity of patients in this distribution is approximately 0.5, which is similar to the acuity that is found in literature.

Table 2.4: Acuity distribution of NICU patients expressed as the number of NICU nurses required to care for one patient with a certain acuity level, source: Hoek, (2015)

Level	Probability	Nurse per patient
1	0.00	0.20
2	0.04	0.25
3	0.39	0.33
4	0.25	0.50
5	0.25	0.67
6	0.07	1.00

2.2.2 Patient rejection

Unfortunately, there are instances in which a NICU is fully occupied and has to reject patients from their own catchment area. NICUs may be forced to reject a patient due to a shortage of personnel or a shortage of beds. However, if a primary NICU has to reject a patient, they still have an obligation to provide the patient with appropriate care. It is then the primary NICU's responsibility to find a bed for the patient at another NICU. So, the primary has to contact other NICU locations to find one that has the capacity to take on an additional patient.

In case a NICU is contacted by another NICU that is looking for an alternative location for one of their patients, the same protocol applies. So, the coordinating nurse and neonatologist evaluate whether the patient can be admitted. However, when a NICU has to reject a patient from another NICU's catchment area, they are not required to put further effort into finding an alternative location for this patient.

2.2.3 Patient transportation

In 2015, approximately 15% of all NICU patients in the Netherlands could not be treated at their primary NICU (RIVM, 2016). It is preferred to transport the patients before birth, antenally, as this poses less risk. If this is not possible, the patient is transported postnatally, which means after birth. Table 2.5 shows the percentage of patients that are from a NICU's own catchment area and the percentage of patients that are from other catchment areas in the year 2015. The table shows that there are some NICUs who mainly treat patients from their own region and some NICUs that spend a greater amount of their capacity on patients from other catchment areas.

Table 2.5: Number of patient transports expressed as the percentage of total patient transports in 2015, source: RIVM (2016)

Region	% of patients from own region	% of patients from other regions
Amsterdam	91.3	8.7
Groningen	87.6	12.4
Leiden	84.0	16.0
Maastricht	91.1	8.9
Nijmegen	74.9	25.1
Rotterdam	92.4	7.6
Utrecht	76.0	24.0
Veldhoven	73.3	26.7
Zwolle	77.2	22.8
Total	84.3	15.7

The reason patients are transported is either because their primary NICU cannot provide the treatment they require or because their primary NICU is fully occupied. When a patient has to be moved from one location to another, transportation means have to be arranged by the primary NICU. The necessities for a patient transport include an ambulance, a neonatologist, and a neonatal nurse. In case the patient is transported before birth, it may also be necessary to include a gynecologist in the transport. If the patient is transported from a general hospital to their primary NICU, the team drives to the general hospital and then returns to their location with the patient (Figure 2.2a). However, if the patient has to be transported to another location, the team picks up the patient at the general hospital, drives to the alternative NICU, and then returns to their own NICU (Figure 2.2b).

The issue with the way the transportation of patients is organised, is that it temporarily removes capacity from a NICU that already has a high occupancy rate. The primary NICU that is forced to reject a patient based on current patient acuity and available staff, now has to remove staff from their NICU in order to transport a patient. Removing personnel from this NICU thus means that capacity is removed from a location that currently needs all the operational capacity that is available. This may cause the primary NICU to temporarily lower the nurse-to-patient ratio or requires the NICU to employ on-call staff. The NICU that has enough capacity to take on an additional patient only has to wait for the patient to arrive.

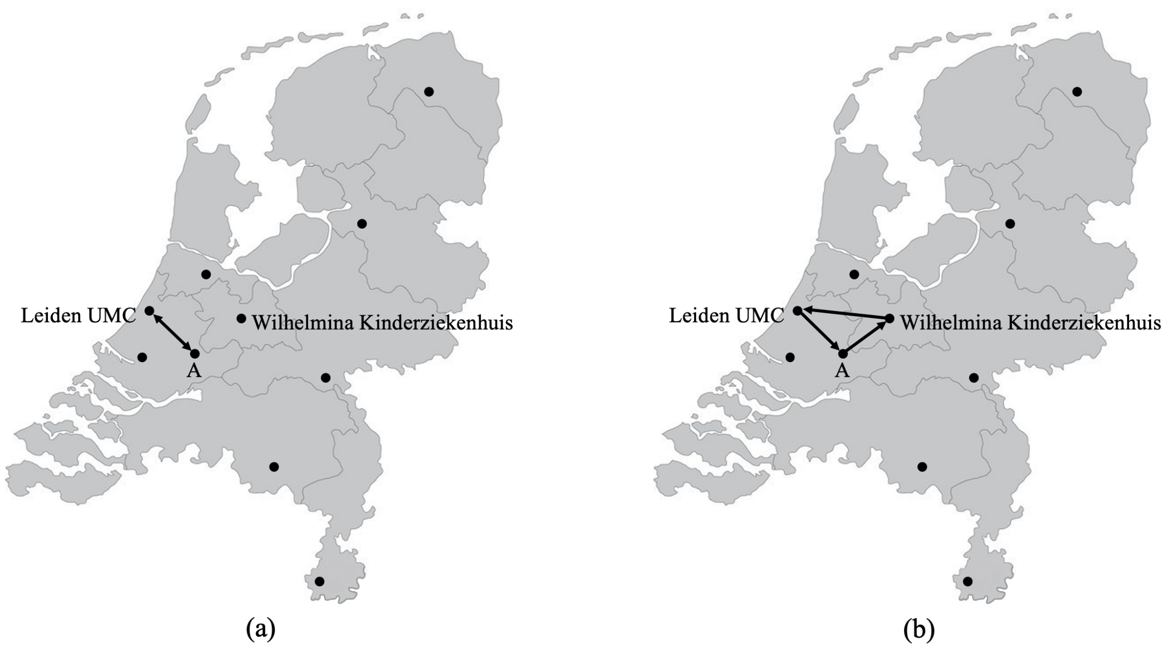


Figure 2.2: Example of patient transport from general hospital A to a NICU location where a) presents the situation where the primary NICU Leiden UMC is able to admit the patient and b) presents the situation where the patient is transported by personnel of primary NICU Leiden UMC to the NICU at Wilhelmina Kinderziekenhuis

2.2.4 Patient discharge

At WKZ, the average length of stay (LOS) of neonates is 11 days. The LOS of patients is exponentially distributed, which means that there may be patients who have to stay at the NICU for several months. A patient may be discharged from the NICU for different reasons as shown in Figure 2.3. Most commonly, the patient is relocated to a MC or HC facility. In case the patient's condition allows it, the patient may be relocated to a regional hospital or even home. Unfortunately, there are also instances in which the patient has deceased.

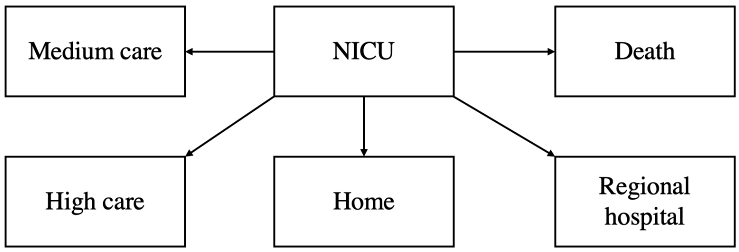


Figure 2.3: Graphical representation of possible reasons for patient discharge

2.3 Baby Zoekt Bed

2.3.1 Baby Zoekt Bed initiative

"BabyZoektBed" (BZB), or "baby searches for bed", is an initiative of the Nederlandse Vereniging voor Kindergeneeskunde (NVK). It was created in 2019 by Willem de Vries, neonatologist at WKZ, and Tim Antonius, neonatologist at the Radboud MC. BZB is a platform that shows real time data on the number of available beds of all NICU locations. Figure 2.4 shows the interface that can be seen when logging into the web page from an account linked to WKZ. Neonatologists that log into the web page can fill out the number of available beds at their location. Simultaneously, they can see the number of available beds at all other locations.

The goal of BZB is to reduce the amount of effort required for finding a bed for a patient when the patient cannot be treated by their primary NICU. Before the BZB initiative, neonatologists had to call other NICU locations to find out whether there were beds available at their location. This process required much time, as this meant that neonatologists often had to call multiple locations before finding a bed for their patient. With the BZB initiative, a neonatologist can immediately see which locations have the capacity to admit an additional patient and thus only have to call one location.

The BZB website offers another benefit, as all the data entered into the website is saved. Before this initiative, there was no available data on the available number of beds at NICU locations. Thanks to the initiative, the logbook of the BZB website can now be used for data analysis on the number of available beds at NICU locations. The analysis presented in the next sections is based on the logs of the BZB website of the year 2020.

In addition to the BZB data, WKZ has also gathered data on the number of operational beds at NICU locations in the past year. This data was gathered by asking all locations to send in their operational capacity on a weekly basis. The data was then aggregated by WKZ for analytical purposes.

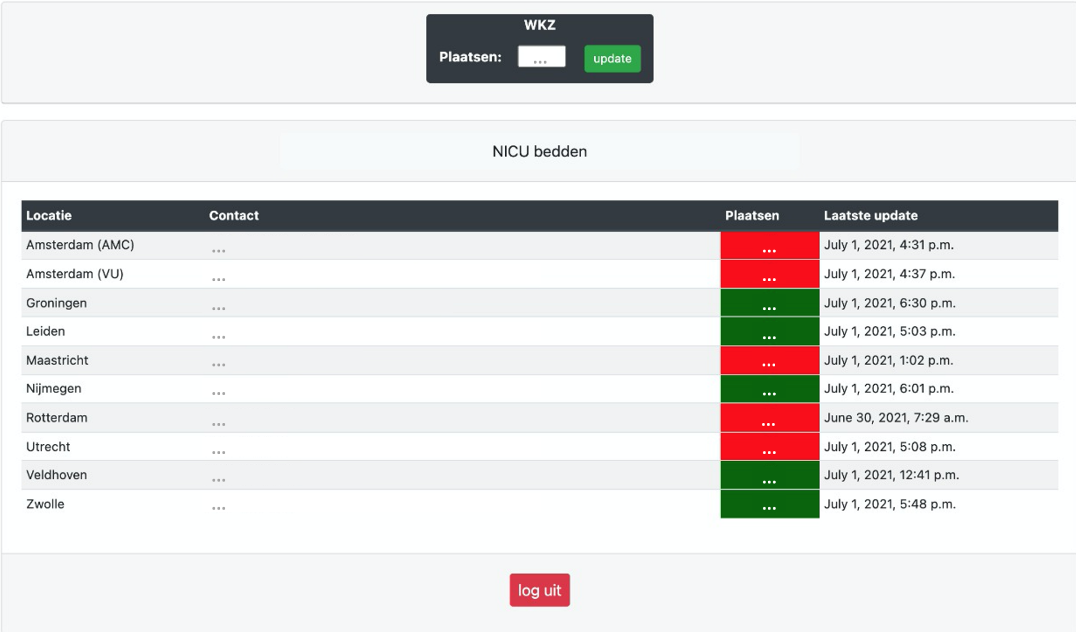


Figure 2.4: Baby Zoekt Bed user interface that shows the real-time available number of beds at all NICU locations as seen from an account linked to WKZ, source: www.babyzoektbed.nl

2.3.2 Operational beds

The NICUs in the Netherlands all have maximum capacities, which depend on the number of beds, the number of available nurses, and the acuity of patients that have been placed at the NICU location. The data on the operational capacities of all NICU locations has been collected by WKZ. This operational capacity, expressed as the number of operational beds, provides information on the maximum operational capacities of NICU locations in the year 2020.

Table 2.6 shows the locations of the neonatal wards, the hospital names, their accompanying maximum number of operational beds, and their average number of operational beds in the year 2020 as derived from the data. Figure 2.5 shows boxplots for the data entries for the number of operational beds at all NICU locations. The data shows that some NICUs experience more variation in the number of operational beds than others. Overall, it can be concluded that the spread of the number of operational beds at single NICU locations is limited.

Table 2.6: Maximum number of operational beds and average number of operational beds at NICU locations in 2020, source: WKZ

Location	Hospital name	Maximum beds (#)	Average beds (#)
Amsterdam	Amsterdam UMC	28	24.4
Groningen	UMC Groningen	18	16.0
Leiden	Leiden UMC	19	17.7
Maastricht	Maastricht UMC	13	11.9
Nijmegen	Radboud UMC	15	12.3
Rotterdam	Erasmus MC	27	27.0
Utrecht	Wilhelmina Kinderziekenhuis	23	22.8
Veldhoven	Máxima MC	15	14.9
Zwolle	Isala	18	16.8

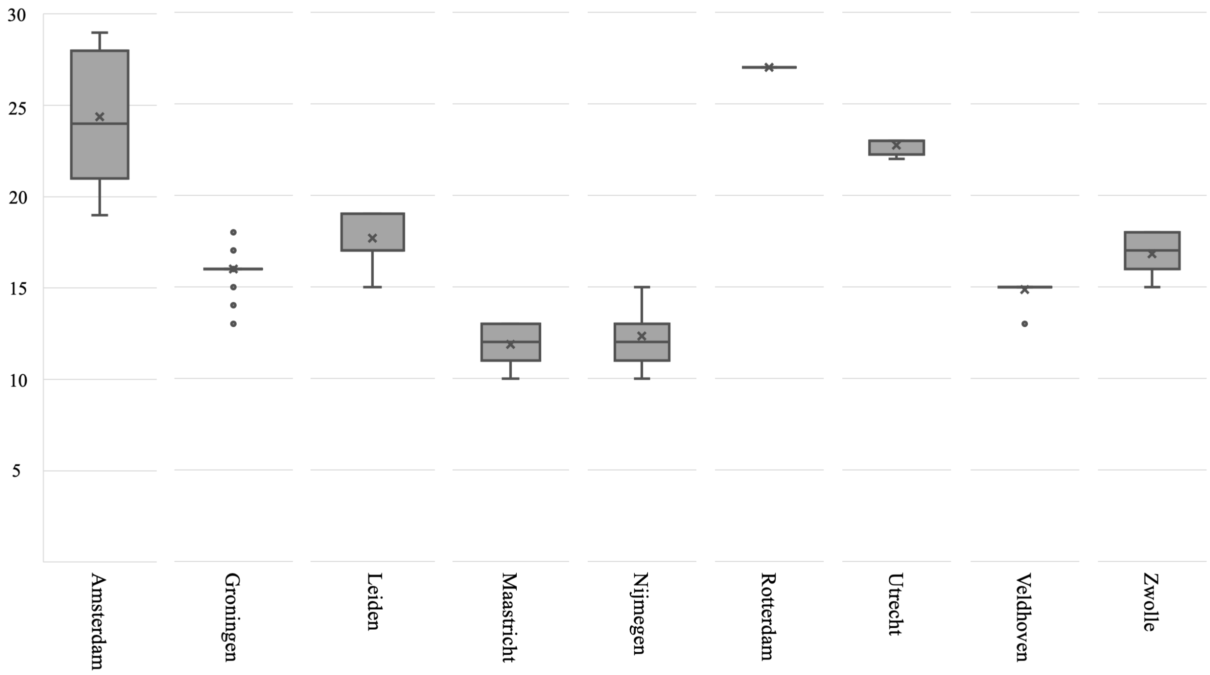


Figure 2.5: Boxplot of the data entries for the number of operational beds at NICU locations, source: BZB logbook

Unfortunately, the data on the number of operational beds does not allow for derivation of a pattern. The data was fitted against multiple distributions (normal, exponential, Poisson), but the results show that their compatibility is not significant. Over time more data will be gathered by WKZ, which might result in the ability to derive a pattern in the data.

What can be derived from the data is an estimation of the number of times a NICU operates with a certain percentage of its maximum operational capacity. The maximum operational capacity is defined as the maximum number of operational beds found in the data gathered by WKZ. For this, the data for all NICU locations where aggregated and the operational capacity of the location was expressed as a percentage of the maximum capacity of this location. Table 2.7 shows the approximate occurrence of a certain level of operational capacity expressed as a percentage of maximum operational capacity in 2020. For example, for 50% of the time, a NICU works at 80% of its maximum capacity.

Table 2.7: Estimation of the distribution of the level of operational capacity at NICU locations, source: WKZ

Percentage of maximum capacity (%)	**Occurrence (%)**
60	5
70	5
80	50
90	10
100	30

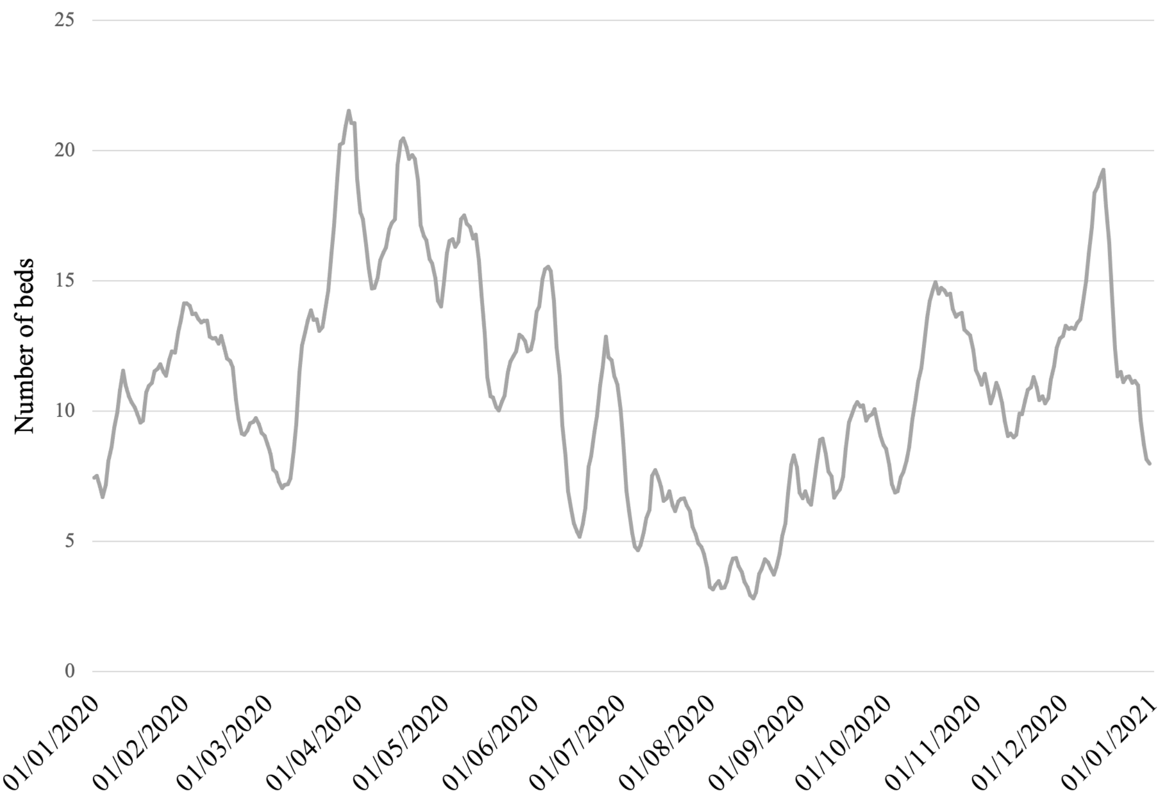
2.3.3 Available beds

In the year 2020, data has been gathered on the number of available beds at each of the nine different NICU locations. The data from the BZB logbook consists of the data logged between January 1st 2020 and December 31st 2020. The usefulness of this data depends on the precision with which neonatologists have updated the information on the website. Neonatologists are free to update the number of available beds as many times as they wish. This is why the data shows that the number of logs per day differ per day and per NICU location. In total, there were 5889 logs in the year 2020. Appendix A shows more detailed information on the number of times individual NICUs have updated this information.

To analyse the data on the available number of beds, several assumptions have to be made. First, we assume that in the time period between two data entries of a NICU location, the number of available beds is equal to the number of available beds in the former data entry. Furthermore, the data set also includes nine logs where a negative number of available beds are logged. However, a negative number of available beds is impossible and further inspection of the data shows that after these entries, another entry with a non-negative number of available beds is logged within seconds. Therefore, the assumption has been made that all data entries that provide a negative number of available beds are errors and are thus excluded from the analysis.

To turn the data into useful information, a representative number of available beds for each day per NICU location has to be created. This is done by calculating the average weighted number of beds for each NICU location and using this number a moving average is calculated. Figure 2.6 shows the weekly moving average of the number of available beds per day in the year 2020. Appendix A shows the weekly moving averages for all individual NICU locations.

Figure 2.6: Weekly moving average of the total number of available NICU beds in the year 2020, n = 5889, source: BabyZoektBed



The moving average for the total number of available NICU beds shows that this number is very volatile. Furthermore, an important takeaway is that, in the year 2020, there was always at least one bed available in the Netherlands. This shows that on a national level, there is enough capacity for the NICU demand in the Netherlands. However, when we look at the individual moving averages of the number of available beds for NICU locations, we see that for many NICU locations, this number rarely exceeds two available beds and for some locations this number often approaches zero.

The fact that NICU locations have so little free capacity explains why patient transport is necessary. Fortunately, the moving average of the total number of available NICU beds in 2020 shows that there is always at least one bed available. This is an important finding for the idea of implementing a flex pool of nurses, because it shows that there is enough capacity in the Dutch neonatal network, but that it is not always available at the right NICU. The flex nursing pool could be a promising solution to this, as it allows for short term capacity allocation between NICUs. By temporarily transferring a nurse from one NICU location to another, we can move capacity to a location that needs it to admit their patient.

Another takeaway from the analysis of the moving averages for the number of available beds at NICUs is that all locations experience periods in which the number of available beds is low. As shown in Appendix A, there are rarely instances where a NICU has five or more available beds and the number of available beds often approaches zero. This data includes the number of beds occupied by patients from different catchment areas, which prevents us from drawing conclusions on whether the NICU capacity in the Netherlands is optimally assigned to the locations.

The allocation of NICU capacity, both the number of beds and the nursing capacity, is historically decided. Because of this, we cannot be sure that the capacity allocation is done in the best way possible. If capacity allocation is done in an optimal way, this will result in the lowest possible number of patient transport. However, the data analysis also shows that there is much fluctuation in the availability of NICU beds which shows that the demand is volatile. So, even if the demand is optimally allocated, the fluctuations in demand would still result in patient transport in demand peaks. This can be deducted from the fact that the number of available beds in the analysis does reach a low number.

This shows that moving capacity from one location to another would not completely solve the problem faced by the NICUs. So, reassigning the nursing capacity to NICUs without increasing overall capacity will not reduce overall patient transport. Furthermore, it is not easy to reassign capacity, as this would require permanent relocation of NICU nurses. This is why we have decided to focus on using flex nurses to to reduce patient transport. The benefit of this is that nurses do not have to be permanently relocated and it can be useful without increasing total NICU capacity.

2.4 Conclusion

This chapter has focused on providing background information on how neonatal care is organised in the Netherlands. The Dutch neonatal network has nine NICU locations, who all have their own catchment area. All regional hospitals have a primary NICU, which is the location that they refer their patients to in case they need neonatal care. On a yearly basis, approximately 2.4% of the children born require neonatal care. This amounts to approximately 4100 patients that are admitted to the Dutch neonatal network every year.

When a patient is in need of neonatal care, the primary NICU is responsible for either admitting the patient to its ward or for finding a bed at another NICU in case they are not able to admit the patient. This decision is based on the number of patients that are already admitted to the ward and the number of nurses and beds that are available. When a patient has to be transported, this requires many resources and temporarily removes personnel from a NICU location that is fully occupied. In the Netherlands, approximately 15% of NICU patients have to be transported to a location other than their primary NICU. This is equal to approximately 600 patient transports per year. The patient is transported preferably antenatally but occasionally postnatally.

There are different personnel types at NICUs, but the availability of nurses poses the biggest constraint on a NICU's capacity. The analysis of the logbook of BZB shows that there was always at least one NICU bed available in the Netherlands in the year 2020. So, based on this data, we see that national capacity of NICUs is sufficient to satisfy national demand. However, the percentage of patient patient transports shows that NICUs do not always have enough capacity to treat all the patients from their catchment area. For this reason, it is interesting to investigate how short-term resource allocation reduces patient transports.

3 LITERATURE REVIEW

The previous chapter elaborated on the problems faced by the Dutch neonatal network caused by the nursing capacity constraints. This chapter aims to answer the second and third research question. Section 3.1 answers the question *"What methods are commonly used to solve or manage capacity constraints resulting from nursing capacity and which of these methods is most appropriate for the Dutch neonatal network?"*. The third research question, *"What are the organisational implications of the chosen staffing shortage solution?"*, is answered in Section 3.2. Both questions are answered by means of a literature review. The steps taken for the literature review for the first question can be found in Appendix B. The approach for the literature review of the second question can be found in Appendix C.

3.1 Proposed solution to nursing capacity shortages

3.1.1 The nursing capacity shortage problem

A nursing shortage can be defined as the difference between the number of nurses required and the actual number of nurses employed at a location (Zarea et al., 2009). The shortage in nursing capacity can lead to inefficiency and a decline in the quality of care (Shamsi and Peyravi, 2020), as a staffing shortage negatively impacts the performance of nurses and increases the patient-to-nurse ratio (Aboshaiqah, 2016). When this happens, patient care and survival is challenged, as higher patient-to-nurse ratios can cause higher mortality rates (Lambrinos et al., 2004). This shows the importance of solving the problem and explains why much research has already focused on proposed solutions to this problem.

Even though many countries across the globe face a nursing shortage, the cause of the problem may vary from country to country (Shamsi and Peyravi, 2020). However, globally two main trends can be identified that lead to the shortage in nurses: an increase in the demand for healthcare services and a decrease in the number of people entering and staying in the nursing profession (Colosi, 2007). The increase in demand for healthcare can be attributed to ageing of the population and an increase in patient acuity (Liu et al., 2013). On the other hand, the reason for the decrease in the number of nurses is due to a declining number of nursing school enrollments and a declining image of nursing (Westendorf, 2007). In addition, the nursing population is ageing, which also contributes to a decreasing nursing population (Shamsi and Peyravi, 2020).

3.1.2 Suggested solutions in literature

Solutions discussed in the literature on how to close the gap between the required number of nurses and the supply of nurses typically focus on increasing the supply of nurses to a level that adequately satisfies demand (Adams, 2009). The strategies for increasing the nursing workforce can be aligned along two broad categories: increasing retainment efforts and increasing recruitment efforts (Neuhauser, 2002). Many of the strategies proposed in literature contribute to both retaining and recruiting nurses.

One solution towards creating a high-retention culture for nursing is to create a higher job satisfaction, as this correlates with nurses' commitment to a hospital and the intent to stay at a job (Rambur et al., 2003). Increasing job satisfaction can be achieved by increasing wages for nurses, however hospitals are not able to significantly increase nurses' pay in the coming years (Lambrinos et al., 2004). Another way to improve job satisfaction includes providing more training and career development opportunities for nurses (Janiszewski Goodin, 2003). Furthermore, improving the working environment can increase retention rates, which can be done by reducing workload (Liu et al., 2013) and by allowing nurses to have a flexible work schedule (Shamsi and Peyravi, 2020).

Increasing the effort put into recruitment for nurses has previously increased the number of nurses (Westendorf, 2007). Initial steps towards improving the recruitment of nurses should focus on improving the image of the nursing profession (Nevidjon and Erickson, 2001). This can spark the interest for nursing in youth and in turn increases the number of enrollments in nursing schools (Cohen et al., 2004). Some papers argue that in addition to increasing the enrollments, the education and training of nursing students should be accelerated (Adams, 2009). Moreover, recruitment efforts could also focus on convincing inactive nurses to return to the profession in order to increase the nursing workforce (Hammer and Craig, 2008).

Other strategies to manage the staffing shortage faced by hospitals include providing nurses with more benefits, for example shared governance (Hess Jr., 2004). Another long term solution would be to support legislation that tackles the nursing shortage (Janiszewski Goodin, 2003). Efforts can also be made to educate the population and promote the benefits of the nursing profession (Zarea et al., 2009).

3.1.3 Selected solution

The previously discussed solutions all focus on how to enlarge the nursing workforce. However, the gap between the demand and supply of nurses can also be closed by using the existing workforce more efficiently (Lambrinos et al., 2004). The literature review shows that using temporary nurses or cross-trained nurses to fill vacant positions has been used as a solution to the nursing shortage problem (McDonald et al., 2019) (Seo and Spetz, 2013) (May et al., 2006) (Inman et al., 2005).

One major benefit of using temporary staffing is that it allows for adaptation to variations in demand, which means that less reserve capacity needs to be maintained (Seo and Spetz, 2013). It can be used as a short-term solution to filling vacancies without requiring permanent nurses to work overtime, which is expensive for hospitals (May et al., 2006). Furthermore, McDonald et al. (2019) found that nurses who are included in a temporary nursing pools have a higher retention rate. These findings are supported by the paper of Inman et al. (2005) who concluded that using temporary staff reduces turnover and costs, and improves quality of care. Therefore, the solution also supports the effects of previously mentioned strategies to the nursing shortage and could function as a more sustainable solution to the problem.

On a tactical level, this solution is interesting as it allows for short-term resource allocation. Benefits can be gained from allowing flexibility in the planning of nurse allocation. For this reason, the remainder of this paper will focus on how this strategy can be used in the context of the capacity related problems in the Dutch neonatal network.

3.2 Temporary staffing

3.2.1 Types and definitions

There are different structures that allow for employing or sharing temporary staff, including "float pools", "cross-trained nurses", "resource teams", and "agency nurses". Even though some of these terms are used interchangeably in literature, there are slight differences in their definitions. In this research, we will distinguish the different types of temporary staffing based on the definitions described below. Figure 3.1 presents a graphical representation of the differences between these nurse types as found in literature.

Float pools, as shown in Figure 3.1a, refer to systems in which nurses are employed by a hospital and trained to work at different departments (Dall'ora and Griffiths, 2017). In this system, nurses are not dedicated to a specific unit but instead are assigned to understaffed wards at the beginning of their shift. Cross-trained nurses (Figure 3.1b) are similar to float nurses, however, they are primarily trained for one unit and may temporarily be placed at other departments only when demand requires it (Fügener et al., 2018). As depicted in Figure 3.1c, resource teams include nurses that are not affiliated with a specific hospital but instead are employed directly be the resource team (Dziuba-Ellis, 2006). The benefit of resource teams is that the nurses included are organised by clinical expertise. Temporary nursing agencies (Figure 3.1d) are similar to resource teams. Mazurenko et al. (2015) define agency nurses as nurses who are employed by an external agency and are temporarily deployed at hospitals as additional staffing. So, in contrast to nurses from resource teams, these nurses do not have a certain expertise and are capable of working in different departments.

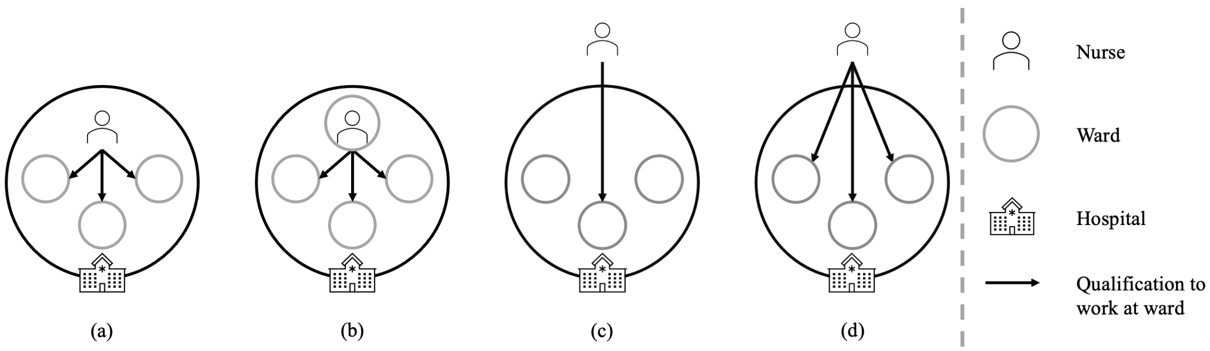


Figure 3.1: Graphical representation of temporary nurse types where a) represents float nurses, b) cross-trained nurses, c) resource team nurses, and d) agency nurses

3.2.2 Implications of temporary nurses

Temporary staff can be used throughout a range of departments, including intensive care units and emergency departments (Mendez de Leon and Stroot, 2013). Temporary nurses can be used in addition to the nurse schedules, which are usually made weeks in advance and therefore not flexible (Schoenfelder et al., 2020). It can result in creating short-term flexibility to efficiently manage and adapt to fluctuations in demand and supply which is why hospitals can benefit from this (Fagefors et al., 2020). The strategy is especially useful in case of unexpected variations due to nurse absences or increased patient acuity (Straw, 2018). Nurses on the other hand, can benefit from cross-training or floating as this strategy offers nurses more care types and variation within their job and exposes nurses to more challenges and learning opportunities (Lebanik and Britt, 2015).

Working at multiple locations means that nurses have to be familiar with the way of working and procedures of multiple hospitals. This is why some literature suggests that there are potential safety issues with the use of temporary staff (Seo and Spetz, 2013) (Senek et al., 2020). Familiarising oneself with the procedures of multiple hospitals is rather complex, which is why some hospitals discourage newly graduated nurses from joining float pools or resource teams and prefer to include more experienced nurses (Crimlisk et al., 2002). When temporary nurses are assigned to a new department, they should be given time for an onboarding or orientation process before the starting their shift in this new environment (Tuttas, 2015) (Roach et al., 2011).

There are contradicting findings concerning the safety of using temporary staff. For example, Pham et al. (2011) argues that temporary nurses cause more severe medication errors than permanent staff, whereas Bae et al. (2015) found that there is no evidence that links temporary staff to increased risk to infections. Aiken et al. (2007) concludes that temporary nurses are not less qualified or competent to work at the departments they have been trained for than permanent staff at these locations and that they do not diminish the quality of care provided. What literature does agree on, however, is that using flex nurses is only safe when they are sufficiently experienced, especially in emergency departments where nurses have to make urgent decisions (NHS, 2021).

3.2.3 Cross-training policies

Fügener et al. (2018) describe different cross-training policies, including chaining, reciprocal pairs, n-to-all, and one-for-each as shown in Figure 3.2. The authors describe the policy of chaining (3.2a) as a situation where every unit trains nurses for one other location. In this way, every float unit can be supplied with additional nurses from a different unit. In the cross-training policy reciprocal pairs (3.2b), units are linked to each other and are able to exchange nurses between the locations. Figure 3.2c shows the n-to-all policy, in which units train nurses to work at all other locations. Finally, the policy one-for-each (3.2d) is a policy in which units train nurses for only one other location, but where combined nurses are trained for all other locations.

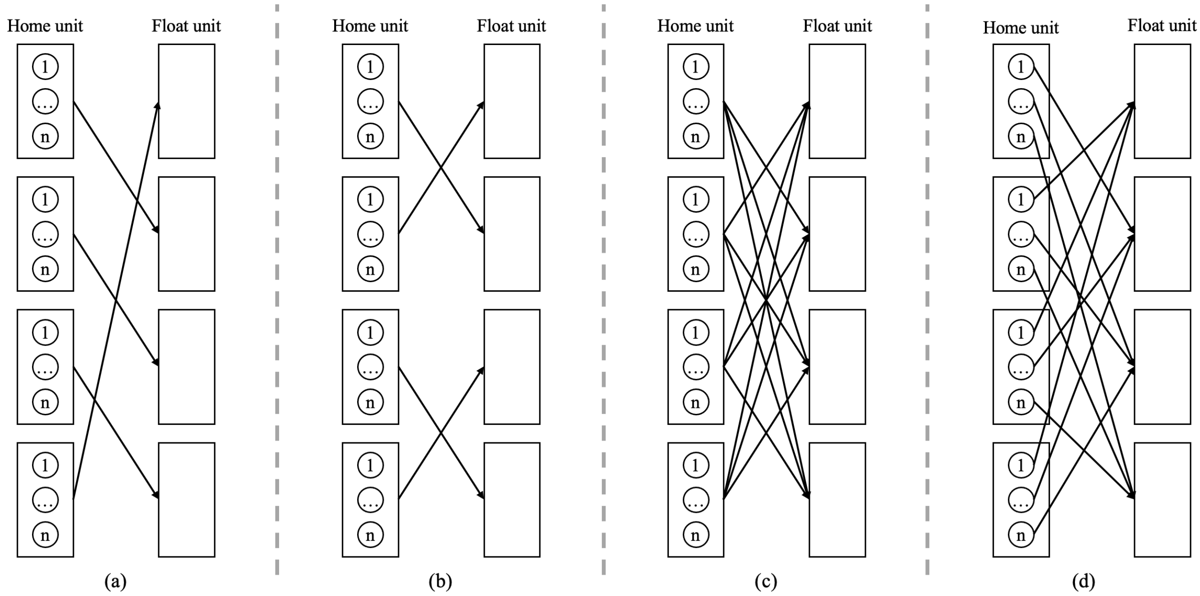


Figure 3.2: Graphical representation of cross-training policies where a) represents the chaining policy, b) the reciprocal pairs policy, c) the n-to-all policy, and d) the one-for-each policy, source: adapted from Fügener et al. (2018)

To ensure adequate quality of care when using temporary nurses, they must be trained to work in different environments, which can be a difficult process (Correia and Goodrow, 2021). One way to ensure nurses are capable and qualified to work at a unit is by pairing them with nurses that have a permanent position at this unit (Manelski et al., 2013). This allows temporary nurses to be trained and to adjust to patient needs at other locations.

3.2.4 Baseline planning

When working with temporary nurses, decisions also have to be made about the baseline planning of the permanent nurses at a ward. Griffiths et al. (2021) propose three different ways to create the staff plan of permanent nurses when temporary nurses can be used to handle fluctuating demand as shown in Figure 3.3. These include a low baseline staff planning, standard baseline staff planning, and high baseline staff planning. The paper defines the low baseline planning (Figure 3.3a) as a planning in which 80% of average demand can be handled through permanent nurses. The standard baseline planning (Figure 3.3b) is based on ensuring that the capacity of permanent nurses is equal to the average demand. A high baseline planning (Figure 3.3c) describes the situation in which the staff plan is set to meet the 90th percentile of demand with permanent nurses. Griffiths et al. (2021) conclude that a low baseline planning results in cost-savings, but that higher baseline rosters lead to increased quality of care.

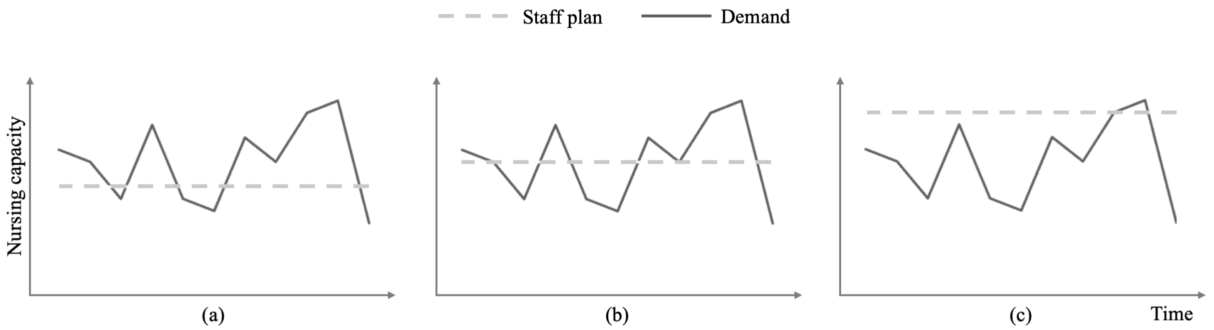


Figure 3.3: Baseline planning policies, where a) represents low baseline planning, b) standard baseline planning, and c) high baseline planning

Dall'Ora et al. (2020) supports this finding and concludes that there is an increased risk for patient safety when hospitals rely highly on temporary nurses. They attribute the increased risk to temporary nurses being less familiar with procedures and ineffective communication. Bae et al. (2010) conclude that due to the disruption of routines, high levels of temporary nurses result in more incidents. It is also important to note that high levels of temporary staff can affect the permanent nurses' job satisfaction (Simpson and Simpson, 2019). When temporary nurses are less familiar with the environment they have been deployed to, there is a greater reliance on permanent staff to manage and guide the temporary nurses (Bajorek and Guest, 2019).

3.3 Conclusion

The first section of this chapter answers the question *"What methods are commonly used to solve or manage capacity constraints resulting from nursing capacity and which of these methods is most appropriate for the Dutch neonatal network?"*. Nursing shortages have been widely studied and many solutions have been proposed. The solutions mainly focus on increasing the nursing population by focusing on retainment of current nurses and recruitment of potential nurses. However, a more promising solution for the problem faced by the Dutch neonatal network might be to use the existing nursing population more efficiently.

Section 3.2 answered the question *"What are the organisational implications of the chosen staffing shortage solution?"* The literature review showed that there are several decisions that have to be made when organising temporary staffing. First, the type of temporary nurses used has to be chosen, which includes decisions about who employs the nurse and whether the nurses provide specialised care. Another decision includes the cross-training policy used. This determines which units nurses can be exchange to and from which units nurses can be received. Finally, the level of baseline planning must be decided, which entails the minimum level of demand that is handled by non-temporary nurses.

4 SIMULATION MODEL

This chapter answers the fourth research question, *"How can we model the Dutch neonatal network and the flex pool of nurses?"* Section 4.1 describes the idea behind the flex pool of nurses and the means to model this and to evaluate its performance. Section 4.2 discusses the assumptions and modelling decisions made. Section 4.3 describes the experimental design of the model. Finally, Section 4.4 describes the experimental approach of the research, including the experiment configurations.

4.1 Model description

4.1.1 Discrete even simulation

The idea for introducing a flex nursing pool in the Dutch neonatal network presented in this research is subject to several major barriers including organisational barriers, financial barriers, legal barriers, etc. These barriers prevent the model from being tested in real life and also pose a risk for the implementation of the idea. Because of this risk, it would be unwise to invest a great amount of time in building an analytical model for testing this idea without knowing whether the idea will actually contribute to reducing patient transport.

To still be able to validate the idea in this research whilst limiting the time required for modelling the flex pool of nurses, we chose to use discrete event simulation (DES) to test the model. The simulation is modelled in Python 3.7 in the Python Programming Language. Python is an open source programming software, so this allows all interested parties to use and experiment with the code created for this research.

4.1.2 Flex nurse pool

The system proposed in this research is based on a combination of different temporary nurse types. Therefore, in this research, the term "flex pool" is introduced. Similar to float nurses and cross-trained nurses, the nurses in the flex pool are primarily employed by one hospital for one specific department and are deployed at another location when demand requires it. However, similar to resource teams and agency nurses, all nurses included in this flex nurse pool are NICU nurses and thus specialised in the type of care they provide. So, the flex pool of nurses consists of NICU nurses from different locations or hospitals that have the same expertise and are willing to temporarily provide care at another location.

The aim of introducing a flex pool of nurses in the Dutch neonatal network is to reduce patient transport. Patient transport is required when a patient is rejected by their primary NICU and transferred to another NICU. As mentioned previously, this is usually not because of a shortage in beds, but because of a shortage in nursing capacity. So, when this instance occurs, the flex nurse pool can provide a different solution. Contrary to the current situation, the NICUs in the simulation are able to temporarily send their nurses who participate in the flex pool to NICU locations that are in need of more nursing capacity. In this way, the nurse temporarily relocates to the NICU location in need of an extra nurse which allows the NICU to admit the patient from their catchment area.

The flex pool of nurses consists of nurses that are willing to work at multiple NICU locations. Every nurse in the pool is employed by one NICU and if the nurse is not required elsewhere, the nurse works at the primary workplace. The nurses in the flex pool are informed before the start of the shift where they are expected to work. The nurses in the flex pool finish their shift at the same NICU as the NICU where they start their shift. So a nurse is not required to work at multiple NICU locations in one shift as this would not result in the most efficient use of the nurses working time.

4.1.3 Key performance indicators

The performance of the model can be evaluated by means of different key performance indicators (KPIs). These KPIs aim to provide valuable information on the performance of the flex pool, more specifically the extent to which patient transport can be reduced.

The first KPI included in the analysis is the number of rejected patients as a percentage of the total incoming patients. As mentioned previously, the scope of the research is set to the Dutch neonatal network. However, it may occur that all NICU locations are fully occupied. In case this happens, patients are transported to a NICU location outside the Netherlands. Since this is not in the scope of the research, these patients are rejected by the model. So, rejected patients are actually patients treated abroad. In the remainder of the paper, we will refer to these patients as rejected patients.

The next KPI is the number of transported patients as a percentage of the total incoming patients. This is the most important KPI as the objective of the research is to analyse whether this can be reduced by introducing a flex pool of nurses. Patients cannot be relocated once they have been admitted to a NICU location, so only incoming patients can be transported. The number of patient transports is expressed as the percentage of the total number of incoming patients in the model.

The final KPI is the percentage of nurse transfers. By keeping track of the number of nurse exchanges, information can be gathered about the extent to which the flex nursing pool is used. The system also saves the number of exchanges between each combination of NICU locations. The KPI on the number of nurse transfers is expressed in two ways. The first is as the percentage of nurse shifts that are worked at a location different than the primary work location of a nurse compared to the number of shifts of all nurses on duty. The second way is the number of nurse shifts worked at at a location different than the primary work location of a nurse expressed as a percentage of the total number of flex nurse shifts.

4.2 Model design

4.2.1 Model assumptions

To model the flex pool of nurses, several assumptions and simplifications of the Dutch neonatal network have to be made. The DES contains four different event types; patient arrival, patient departure, shift changes, and week changes. A flowchart of the simulation model is shown in Figure 4.1. The four events in the simulation model all trigger a sequence of steps to be followed, which are discussed in more detail in Appendix D. This section will discuss the most important design decisions and assumptions used in the model.

The assumption is made that the LOS of patients does not depend on the NICU location that treats them. Moreover, the verdict on whether or not it is possible for a NICU to admit an additional patient, is dependent on the availability of beds and the availability of nurses. The availability of beds is determined by looking at the number of already admitted patients and the number of physical beds at the primary NICU. The availability of nurses is checked by calculating the cumulative acuity of the admitted patients and comparing this number with the number of nurses present at the NICU. If there is not enough capacity to admit an additional patient, the patient cannot immediately be placed at the primary NICU. In the model, it is assumed that the patient can then can be placed in a temporary bed at the primary NICU. The patient will be assigned a permanent bed at the next shift change.

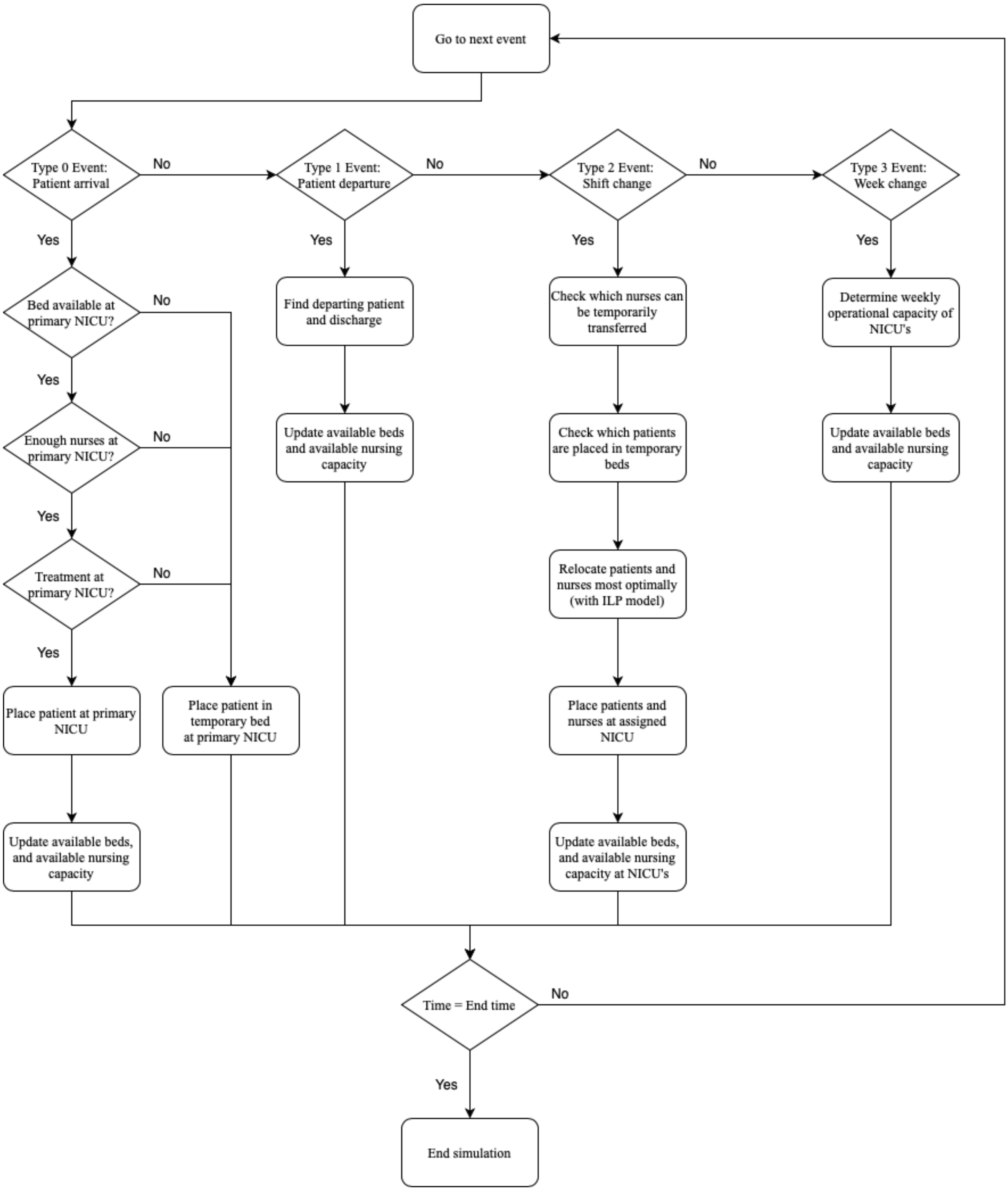


Figure 4.1: Flowchart of the discrete event simulation model. There are four main event types: patient arrivals, patient departures, shift changes, and week changes. These types of events all trigger a set of actions in the model.

In the model, it is assumed that each NICU works with three nurse shifts per day of eight hours each. So, there are three instances a day where all NICU's simultaneously have a shift change. Another assumption is that nurses only have to work at one NICU during their shifts. So, a nurse starts and ends their shift at the same NICU. This allows the model to utilise the nurses working hours in the most efficient way.

Furthermore, it is assumed that there is no difference in the type of care that NICU nurses are able to provide. In real life there are some tasks that only a more senior nurse can perform, but these are mainly organisational and do not include any tasks relating to providing care for patients. Also, the perception at NICUs is that there are enough senior nurses to perform the organisational tasks required. Therefore, we assume that all nurses are able to provide all care types required by patients. The organisational tasks performed by more senior nurses are thus considered outside the scope of this research.

The home locations of patients and nurses are considered out of scope for this research. So, the assumption is made that travel times of patients and nurses can be calculated from their primary NICU or primary work location. The distances between the locations are calculated by finding the shortest route from one location to another. Table 4.1 shows the distances between NICU locations expressed in kilometers. From this, the priority matrix for NICU locations can be derived, which is shown in Table 4.2. So, the prioritisation matrix can be used when the model tries to find an alternative NICU location for patients or when the model tries to find a flex nurse.

Table 4.1: Distance matrix NICU locations expressed in kilometers

Location	**Amsterdam**	**Groningen**	**Leiden**	**Maastricht**	**Nijmegen**	**Rotterdam**	**Utrecht**	**Veldhoven**	**Zwolle**
Amsterdam	0	176	47	204	109	77	40	117	111
Groningen	176	0	219	337	196	250	187	261	104
Leiden	47	219	0	226	131	39	63	138	155
Maastricht	204	337	226	0	135	201	179	92	236
Nijmegen	109	196	131	135	0	116	87	75	96
Rotterdam	77	250	39	201	116	0	63	113	152
Utrecht	40	187	63	179	87	63	0	92	86
Veldhoven	117	261	138	92	75	113	92	0	160
Zwolle	111	104	155	236	96	152	86	160	0

Table 4.2: Priority matrix NICU locations

Location	**Priority 1**	**Priority 2**	**Priority 3**	**Priority 4**	**Priority 5**	**Priority 6**	**Priority 7**	**Priority 8**	**Priority 9**
Amsterdam	Amsterdam	Utrecht	Leiden	Rotterdam	Zwolle	Veldhoven	Nijmegen	Groningen	Maastricht
Groningen	Groningen	Zwolle	Amsterdam	Utrecht	Nijmegen	Leiden	Rotterdam	Veldhoven	Maastricht
Leiden	Leiden	Amsterdam	Rotterdam	Utrecht	Zwolle	Veldhoven	Nijmegen	Groningen	Maastricht
Maastricht	Maastricht	Veldhoven	Nijmegen	Utrecht	Amsterdam	Rotterdam	Zwolle	Leiden	Groningen
Nijmegen	Nijmegen	Veldhoven	Utrecht	Zwolle	Amsterdam	Rotterdam	Maastricht	Leiden	Groningen
Rotterdam	Rotterdam	Leiden	Utrecht	Amsterdam	Veldhoven	Nijmegen	Zwolle	Maastricht	Groningen
Utrecht	Utrecht	Amsterdam	Rotterdam	Leiden	Zwolle	Veldhoven	Nijmegen	Maastricht	Groningen
Veldhoven	Veldhoven	Maastricht	Utrecht	Nijmegen	Amsterdam	Rotterdam	Leiden	Zwolle	Groningen
Zwolle	Zwolle	Utrecht	Groningen	Amsterdam	Nijmegen	Leiden	Rotterdam	Veldhoven	Maastricht

4.2.2 Integer linear problem for shift changes

When a shift change event occurs in the model, the flex nurses in the upcoming shift are assigned to a NICU location and the patients that are placed in temporary beds are assigned to permanent positions. The model assumes that patients can only be transported during shift changes. This deviates from real life, as in reality patients are usually transported to the NICU that is going to treat them before the patient is born. The reason the model assumes this is because nurses can only be reassigned during the next shift change. So, if the model would not allow for this simplification of reality, patients are not optimally assigned to NICUs.

The integer linear problem (ILP) is used to optimally allocate flex nurses and patients to NICUs. The nurses that do not participate in the flex pool and the patients that are already placed at a NICU location inputs for the model. The objective of the ILP is to minimise the number of patients transported. In case a patient does need to be transported, the model relocate the patient to the nearest available NICU. Furthermore, the model takes into account the distances that flex nurses have to travel. The sets, parameters, and variables used are as follows:

Sets

N	set of locations
P	set of patients

Parameters

c_j	$j \in N$	cumulative patient acuity at location j
d_{ij}	$(i,j) \in N$	distance between location i and location j
f_{ij}	$(i,j) \in N$	1 if exchange is allowed between i and j, 0 if otherwise
g_a	$a \in P$	acuity of patient a
h_j	$j \in N$	number of fixed nurses at location j
m_j	$j \in N$	maximum number of beds at location j
o_j	$j \in N$	number of occupied beds at location j
v_j	$j \in N$	number of flex nurses from location j to be allocated in upcoming shift
t_a	$a \in P$	number of beds required for patient a (necessary in case of twins)
p_1		penalty for transporting patient
p_2		penalty for temporarily under-staffing of location
p_3		penalty for rejecting a patient

Variables

x_{aij}	$a \in P, (i,j) \in N$	1 if patient a from location i is treated at location j, 0 if otherwise
z_{ai}	$a \in P, i \in N$	1 if patient a from location i is rejected (transported abroad), 0 if otherwise
y_{ij}	$(i,j) \in N$	number of flex nurses of location i assigned to location j in the next shift
b_j	$j \in N$	slack variable to temporarily allow understaffing

Objective

$$\min \sum_{a\in P}\sum_{i\in N}\sum_{j\in N} x_{aij}d_{ij} + \sum_{a\in P}\sum_{i\in N}\sum_{j\in N} x_{aij_{i\neq j}}p_1 + \sum_{i\in N}\sum_{j\in N} y_{ij}d_{ij} + \sum_{j\in N} b_j p_2 + \sum_{a\in P}\sum_{i\in N} z_{ai}p_3 \tag{4.1}$$

Constraints

$$\sum_{i\in N}\sum_{j\in N} x_{aij} + \sum_{i\in N} z_{ai} = 1 \qquad \forall a \in P \tag{4.2}$$

$$\sum_{a\in P}\sum_{i\in N} x_{aij}t_a + o_j \leq m_j \qquad \forall j \in N \tag{4.3}$$

$$\sum_{a\in P}\sum_{i\in N} x_{aij}g_a + c_j \leq \sum_{i\in N} y_{ij} + h_j + b_j \qquad \forall j \in N \tag{4.4}$$

$$y_{ij} \leq v_i f_{ij} \qquad \forall (i,j) \in N \tag{4.5}$$

$$\sum_{j\in N} y_{ij} = v_i \qquad \forall i \in N \tag{4.6}$$

$$x_{aij} \in 0,1 \qquad \forall a \in P, (i,j) \in N \tag{4.7}$$

$$z_{ai} \in 0,1 \qquad \forall a \in P, i \in N \tag{4.8}$$

$$y_{ij} \in \mathbb{Z}^+ \qquad \forall (i,j) \in N \tag{4.9}$$

$$b_j \in \mathbb{Z}^+ \qquad \forall j \in N \tag{4.10}$$

In the model, decisions have to be made on where to allocate flex nurses and if and where to place patients. The allocation of nurses is done by means of the y variable and it indicates whether a nurse will work at their primary work location or at another location. The x variable is used to assign a patient to a location, which may be their primary NICU or another NICU. When a patient cannot be treated by the Dutch neonatal network, they have to be rejected which is what variable z is used for. The variable b is a slack variable that is introduced to ensure a feasible model. The objective function of the ILP, equation 1, consists of five components. The first component is the distance travelled by patients. The second component is a penalty that is given for every patient that is not treated at their primary NICU. The third component is the distance travelled by all nurses. The fourth component is a penalty that is given for temporarily allowing a nursing shortage at a location. The fifth component is a penalty given for every patient that is rejected by the system.

Equation 2 presents the constraint that a decision must be made for all patients. This decision can either be to place the patient at a NICU location, or to reject the patient. If the patient is rejected, this means that the patient is treated abroad. In the model however, the patient will be lost to the system as NICUs outside the Netherlands are considered out of scope. Equation 3 checks that the number of assigned patients to a location does not exceed the number of available beds. The number of incoming patients that are assigned to a NICU is multiplied by the number of beds required for this patients. This is because twins are modelled as one patient in the simulation.

The next constraint, presented in equation 4, checks whether a NICU location has enough capacity to admit an additional patient. On the left side of the equation, the cumulative acuity of incoming patients that are assigned to the NICU is added to the acuity of the patients that have previously been admitted. This number should be less than or equal to the number of fixed nurses at this location plus the number of flex nurses assigned to this location as shown on the right side of the equation. The slack variable b is incorporated in this equation to temporarily allow understaffing at a NICU. This may be necessary as the number of fixed nurses at a location varies. So, when this number decreases, the location may end up with a cumulative patient acuity that is higher than the number of nurses. The slack variable b ensures that the model will still be feasible when this happens. The penalty for accepting understaffing is sufficiently higher than the penalty for rejecting a patient, so the model will not assign patients to this location in case it already has a nursing shortage. The penalty also ensures that the model will try to avoid understaffing by sending additional flex nurses to the location when possible.

Equation 5 makes sure that there are no nurse exchanges between locations that are not allowed to share nurses. Equation 6 checks that the number of nurses deployed at locations other than their own does not exceed the maximum number of nurses included in the flex pool. Equations 7 and 8 ensure that the variable for assigning patients, x, and the variable for rejecting patients, z, are binary and may only have the values zero or one. Finally, equations 9 and 10 state that the variable for assigning nurses, y, and the slack variable b are in the set of positive integers.

4.3 Experimental design

4.3.1 Warm-up period

The network modelled in the DES starts with empty NICU wards. This causes the model to experience transient system behaviour at the start of the simulation. For example, when all NICUs are empty, every patient can be placed without needing transportation. This data does not accurately reflect the number of patients that need to be relocated and should therefore not be taken into consideration when analysing the model. For this reason, a warm-up period is implemented at the start of each simulation run.

The warm-up period is determined by using the Welch's graphical procedure. Five independent runs of ten years are done and the average number of patients for each day in the simulation is determined. Then, the moving averages for the windows 10, 50, 200 and 500 are calculated and plotted over time. Figure 4.2 shows the moving average over time, where each data point represents one day. Figure 4.3 shows only Welch's procedure for the window 500. From this figure, it can be seen that the line stabilises after approximately 300 days. Therefore, the warm-up period for the simulation model has been set to one year (365 days).

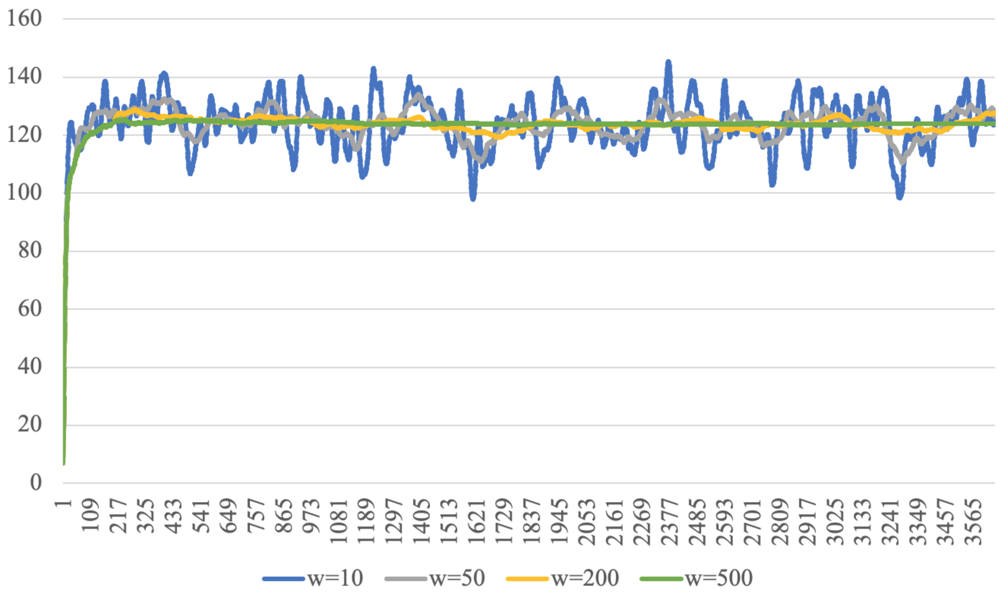


Figure 4.2: Welch's graphical procedure for windows 10, 50, 200 and 500 for the number of patients in the system (n = 3650 days)

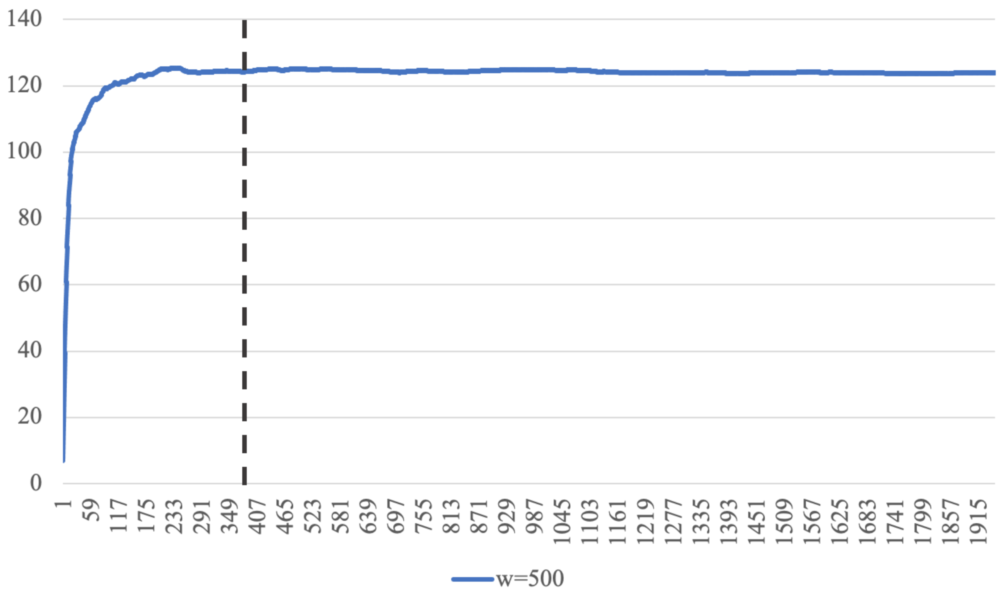
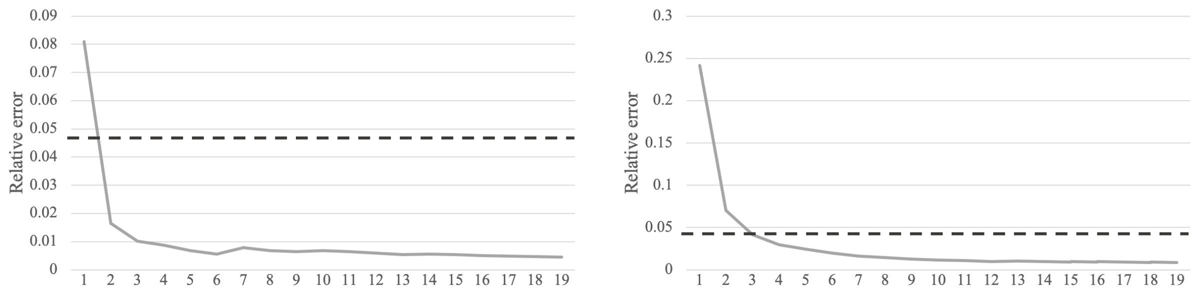


Figure 4.3: Welch's graphical procedure with window 500 shows the number of patients in the system stabilises after approximately 300 days. The warm-up period is set to one year (365 days) (n = 3650 days).

4.3.2 Replications

The model needs to be run multiple times to obtain data with a maximum relative error of at most 0.05 for the KPIs identified for the model. When aiming for a relative error of 0.05, the actual relative error of the model is 0.048. The data used for the calculation of the number of required replications is gathered by running twenty-five independent replications of the simulation. The input for the number of required replications is the number of rejected patients and the number transported patients. The calculations show that the number of rejected patients needs two replications and the number of transported patients needs three replications. However, to be sure that the maximum relative error is attained, we have set the number of replications equal to ten.



(a) Relative error for number of rejected patients

(b) Relative error for number of transported patients

Figure 4.4: Graphical representation of the relative error per run for the number of rejected patients (a) and the number of transported patients (b). To obtain a relative error of at most 0.05 for the KPIs, the number of replications should be three at minimum.

4.3.3 Model validation

The model was validated by checking the certain data outcomes of the simulation without the flex pool with experts in the field. The data checked included the number of patients, number of rejected patients, number of patients treated from own catchment area, and the number of patients treated from other catchment areas. Furthermore, the outcomes were also checked with the percentages as presented in Chapter 2.

Overall, the opinion of the experts is that the model reflects reality in an adequate way. The number of patients treated roughly represents the actual number treated at the NICUs. However, the experts did mention that the number of rejected patients might be slightly higher than what is experienced in real-life. This is as expected, as in real-life an emergency bed is often used to place a patient from a NICU's own catchment area. Moreover, some a NICU reserves at least one free bed for a patient from their own catchment area. However, the model does not allow such an action, which causes the number of rejections to be higher.

Another notable issue raised in the conversations on the validation of the model is that the more centrally located NICUs have a relatively high percentage of rejections and high percentage of patients treated from other catchment areas. This again has to do with the fact that NICUs in the model do not reserve a bed for their own catchment area as this is not an agreed upon policy between NICUs.

With this in mind, the experts say that the model reflects real-life and may be used to analyse the potential benefit of implementing a flex nursing pool in the Dutch neonatal network.

4.4 Experimental approach

4.4.1 Configurations

The model allows for testing the flex pool of nurses with different organisational rules. This allows the model to be tested in multiple settings and in this way it can provide valuable insight in the most optimal use of the flex pool of nurses. For this research, the experiments are performed that include variation in the number of participating nurses, the number of participating locations, and the identified cross-training policies.

Nurses might resist participating in the flex pool of nurses as it may result in more travel time or more stress as they need to be familiar with not just one NICU, but multiple. Over time, this problem may be resolved by for example informing nurses of the benefits offered by working on multiple NICU's or by offering better compensation. However, there is reason to believe that nurses might not be willing to participate, especially in the early stages of implementing the flex pool. For this reason, it is important that the model allows for experimentation with the number of participating nurses per location. Also, it allows for investigating what the improvement potential of each additional nurse that participates in the flex pool.

Another valuable experimental setting in the model is the inclusion or exclusion of certain NICU locations. As mentioned, long travel times for nurses might make them less likely to participate in the flex pool. Therefore, if the model is able to guarantee a maximum travel time for nurses, it may result in more willingness to participate. When looking at the geographical distribution of NICU's, we see that there are some NICU locations that are less centrally located than others which would result in significantly more travel time if nurses from these location participate in the flex pool. So there is reason to believe that nurses from, for example, the NICU locations in Groningen and Maastricht are less willing to participate in the flex pool. This is why the model allows for exclusion of certain NICU locations and for testing the model with only the centrally located NICU locations.

As identified in the literature review, there are different cross-training policies (Figure 3.2) that can be used in the flex pool of nurses. These cross-training policies all have advantages and disadvantages. The cross-training policies chaining, reciprocal pairs, and one-for-each all have the advantage that participating nurses only have to be trained for their primary work location and one additional NICU location. The disadvantage is that these cross-training policies offer less flexibility. The cross-training policy n-to-all on the other hand, offers great flexibility but forces nurses to be familiar with the procedures and way of working of all other NICU locations. This can place great stress on nurses and requires more training time. The model thus allows for experimenting with different cross-training policies to be able to make a trade-off between the organisational complexity of the flex pool and the greatest potential reduction in patient transport.

For each of these factors, three experimental settings have been identified. For the number of participating nurses, the three settings include one participating nurse, two participating nurses, and five participating nurses. National guidelines state that each NICU must always have at least ten to twelve open beds. So, when the configurations say that there are five participating nurses, this means that there are five participating nurses available only if there are also still five nurses at the primary NICU. The selections of locations include all locations, all locations except Groningen and Maastricht, and only including the randstad locations. Finally, the cross-training policies included in the research are n-to-all, reciprocal pairs, and chaining. The total number of experiments will thus amount to 27. In addition, a baseline measurement will be run with zero participating nurses. In total, this means that there are 28 experiments.

4.4.2 Sensitivity analysis

After running the experiments, the two most promising experiments will be selected for a sensitivity analysis on certain input parameters. This is done to test the robustness of the model in case estimations of input parameters are not representative for real-life. The input parameters chosen to include in the sensitivity analysis are the number of patients, the LOS of patients, and the patient acuity. The experiments selected will be run with a 10% decrease and a 10% increase compared to the values used in the experiments for the parameters number of patients and LOS of patients. The values for the patient acuity in the sensitivity analysis will also differ. Scheduling at WKZ is done by using a fixed patient acuity of 0.5. Therefore, in the sensitivity analysis we will use this value to check whether the positive results will uphold for the way WKZ schedules.

4.5 Determination of cross-training policies

4.5.1 Reciprocal pairs policy

To analyse the reciprocal pairs cross-training policy, we first have to determine how to execute this policy. In the reciprocal pairs policy, locations are paired and can share nurses between each pair. In this way, floating between NICU's is possible whilst limiting the number of locations nurses have to be familiar with to only two. The pairs are made by ensuring the least amount of cumulative travel time for nurses and calculated for each combination of included locations in the experiments. This means that the pairs are made for the situation where all locations are included, where all locations are included except Groningen and Maastricht, and where only the randstad locations are included.

The reciprocal pairs policy can be modelled as a capacitated vehicle routing problem (CVRP). Every NICU location in the network is a location with a demand of one. The NICU locations also represent the depots. The number of vehicles in the CVRP is equal to the number of locations divided by two and their capacities are equal to two. In case of an uneven number of locations, the number of vehicles is equal to the number of locations divided by two rounded down. The capacities of the vehicles are equal to two and one vehicle has a capacity of three. In this way, the model finds the shortest routes between all locations, and identifies the shortest cumulative distance for the reciprocal pairs policy.

The formulation of the CVRP is shown below. Constraints two and three ensure that all locations are visited and constraint four tells the model that the vehicles also leave all locations. The capacity of the vehicles are managed by the fifth constraint. Constraint six and seven check the availability of vehicles. Constraint eight makes sure that there are no subtours. The final constraint, number nine, states that the decision variable is binary.

Sets

N	set of all locations
M	set of all depots
V	set of all locations and depots
K	set of all vehicles

Parameters

d_{ij}	$(i,j) \in N$	distance between location i and location j
q_i	$iinN$	demand of location i
p_k	$kinK$	capacity of vehicle k

Decision variables

x_{ij}	$(i,j) \in N$	1 if vehicle k is used for arc *(i,j)*, 0 if otherwise

Objective

$$\min \quad \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} x_{ijk}d_{ij} \tag{4.1}$$

Constraints

$$\sum_{i\in V}\sum_{k\in K} x_{ijk} = 1 \qquad \forall j \in N \tag{4.2}$$

$$\sum_{j\in V}\sum_{k\in K} x_{ijk} = 1 \qquad \forall i \in N \tag{4.3}$$

$$\sum_{i\in V} x_{ihk} - \sum_{j\in V} x_{hjk} = 1 \qquad \forall k \in K \forall h \in V \tag{4.4}$$

$$\sum_{i\in V} q_i \sum_{j\in V} x_{ijk} \leq p_k \qquad \forall k \in K \tag{4.5}$$

$$\sum_{i\in M}\sum_{j\in N} x_{ijk} \leq 1 \qquad \forall k \in K \tag{4.6}$$

$$\sum_{j\in M}\sum_{i\in N} x_{ijk} \leq 1 \qquad \forall k \in K \tag{4.7}$$

$$y_i - yj + (M+N)x_{ijk} \leq N + M - 1 \qquad For 1 \leq i \neq j \leq N and 1 \leq k \leq K \tag{4.8}$$

$$x_{ijk} \in 0, 1 \qquad \forall (i,j) \in N \forall k \in K \tag{4.9}$$

The identified pairs for are shown in Figure 4.5. Because the NICU network in the Netherlands has an uneven number of locations, the choice was made to add the remaining location to one of the pairs. This is done for experiments in which all locations are included (Figure 4.5a) and experiments for which all locations are included except for Groningen and Maastricht (Figure 4.5b).

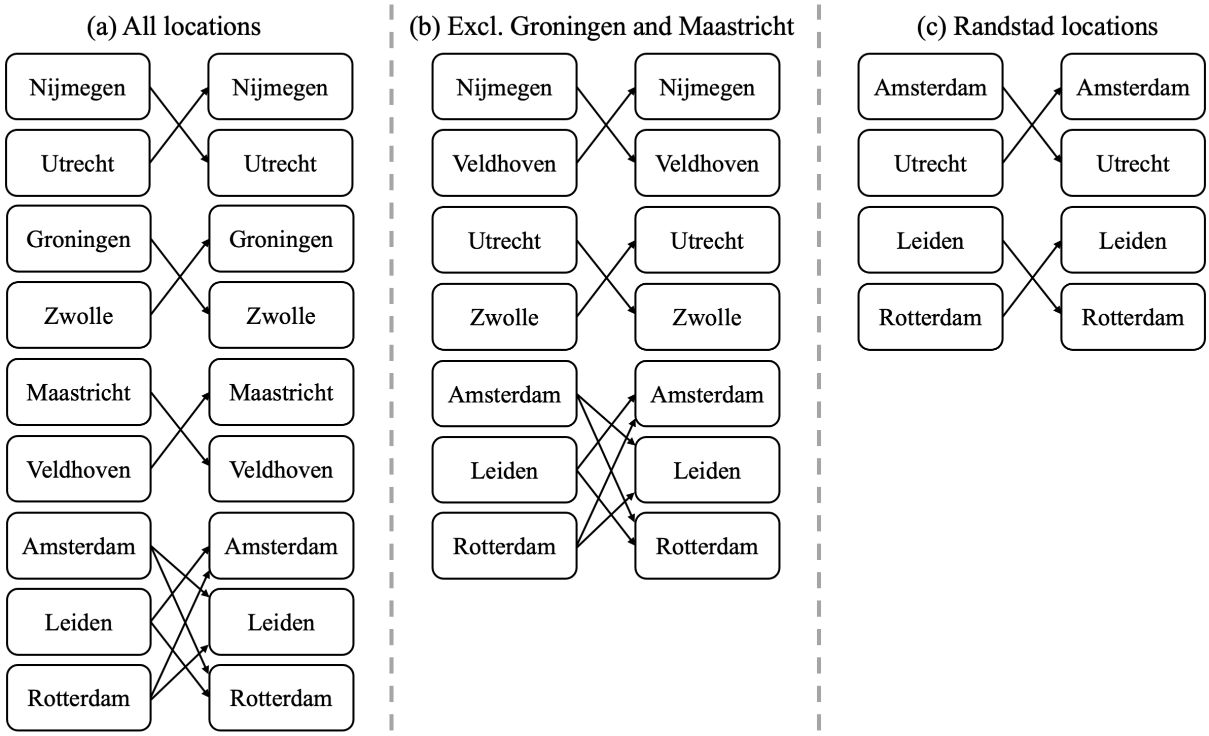


Figure 4.5: Allowed nurse exchanges in the reciprocal pairs cross-training policy determined by a capacitated vehicle routing problem that minimises total travel distance

4.5.2 Chaining policy

Similar to the reciprocal pairs policy, the chaining cross-training policy also has to be determined. Again, this is done for the three combinations taken into account in the experiments for this research. As mentioned previously, the chaining policy allows each NICU location to send nurses to one flex location and allows each NICU location to receive nurses from one flex location.

The chain is determined by creating the shortest route possible between the NICU locations included in the flex pool and this can be calculated by modelling the system as a traveling salesman problem (TSP). The TSP can be formulated as shown below. The first constraint states that all cities must be visited. The second constraint ensures that each city that is visited is also exited. The third constraint ensures that there are no subtours and the final constraint is a binary constraint for the decision variable.

Sets

N	set of all locations
S	set of all subtours

Parameters

d_{ij}	$(i, j) \in N$	distance between location i and location j

Decision variables

x_{ij}	$(i, j) \in N$	1 if arc *(i,j)* is in the tour, 0 if otherwise

Objective

$$\min \quad \sum_{i \in N} \sum_{j \in N} x_{ij} d_{ij} \tag{4.1}$$

Constraints

$$\sum_{i \in N} x_{ij} = 1 \qquad \forall j \in N \tag{4.2}$$

$$\sum_{j \in N} x_{ij} = 1 \qquad \forall i \in N \tag{4.3}$$

$$\sum_{i,j \in S} x_{ij} \leq |S| - 1 \qquad \forall S \in N \tag{4.4}$$

$$x_{ij} \in 0, 1 \qquad \forall (i, j) \in N \tag{4.5}$$

Since the model is analysed with different combinations of participating locations, the shortest route is calculated for each variation. The tour can be followed clockwise or counterclockwise. Figure 4.6 shows one of these two directions. The reason this route is chosen instead of the other option is because this route minimises the distances travelled from the larger NICU wards (Amsterdam, Rotterdam, and Utrecht). We will test the reverse route for the configurations in which all locations are included. If the results of the configurations with this policy show remarkable results in terms of patient transports or nurse transfers, we will run additional experiments with the reversed route.

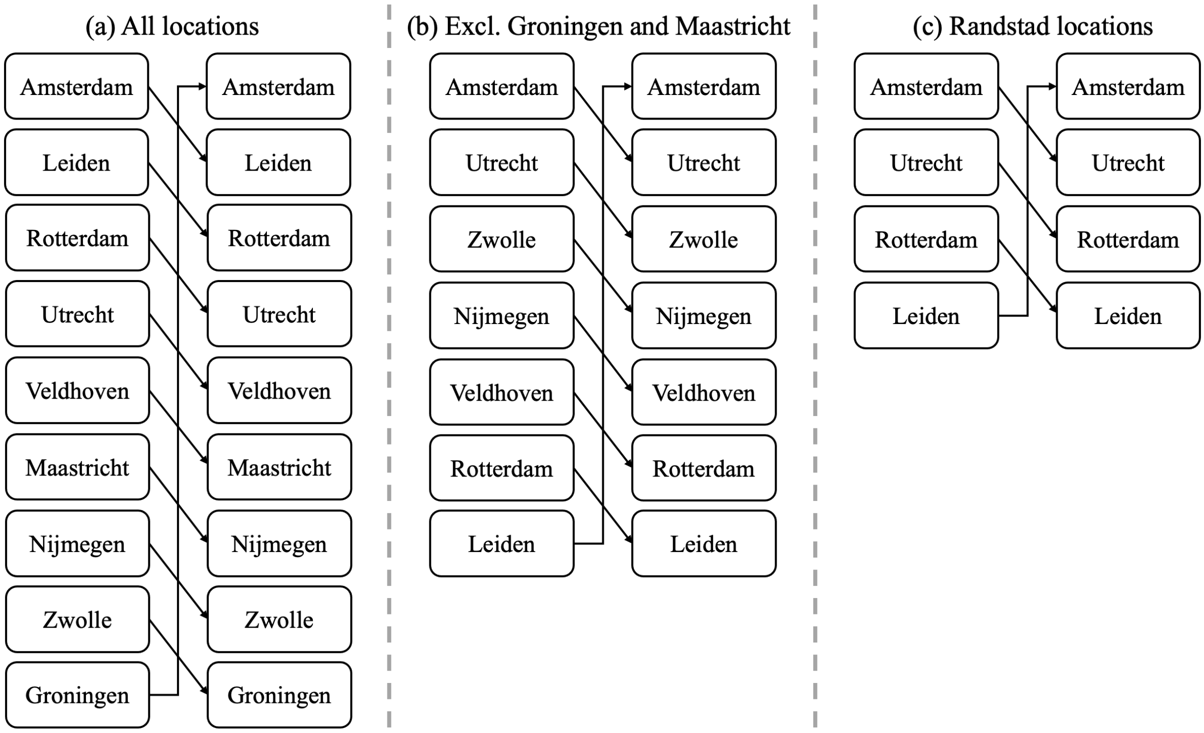


Figure 4.6: Allowed nurse exchanges in the chaining cross-training policy determined by a traveling salesman problem that minimises total travel distance

4.6 Conclusion

This chapter has focused on answering the research question *"How can we model the Dutch neonatal network and the flex pool of nurses?"*.

The flex nursing pool is defined as a pool that nurses can participate in when they are willing to work at multiple locations. The nurses in the pool all have a primary work location, but they are temporarily transferred to other NICU locations if demand requires it. The method chosen to model the flex pool of nurses is a discrete event simulation, as this allows for accurate representation of reality. There are different event types in the simulation, each of which triggers a set of actions. The model assumes that patients and nurses can only be reassigned to a different NICU during shift changes. For this, an integer linear problem is included that assigns patients and nurses to a NICU. This is done based on minimising patient transport and travel distances for nurses.

The key performance indicators identified to analyse the performance of the system are the percentage of rejected patients, the percentage of transported patients, and the percentage of nurse transfers. The experiments in the research are aimed at varying the number of participating nurses, the number of participating locations, and the used cross-training polices. The input parameters included in a sensitivity analysis are the number of patients, the length of stay of patients, and patient acuity. The two best performing experiments will be included in the sensitivity analysis.

5 RESULTS

This chapter aims to answer the fifth research question, *"What are the effects of different policies concerning the flex pool of nurses on the number of patient transfers and the number of nurse exchanges?"* First, we will present a baseline measurement of the simulation model without using the flex nursing pool in Section 5.1. Then, in Sections 5.2, 5.3, and 5.4 we will present the results of the experiments that are performed for each cross-training policy. Section 5.5 will compare the outcomes of the different cross-training policies. Finally, Section 5.6 presents a sensitivity analysis for the two most promising experiments.

5.1 Baseline measurement

To be able to judge the performance of the flex pool, we need to compare its results to a baseline performance that reflects the current situation in the Dutch neonatal network. The baseline measurement used to compare the performance of the flex pool of nurses to, is created by running the model without including any flex nurses in the system. The relevant KPIs of the baseline measurement of the model are the number of rejected patients and the number of transported patients as a percentage of the total number of patients. The results are presented by means of a 95% confidence interval (CI), which means that with a certainty of 95% we can say that the interval contains the true mean of the KPI.

The baseline measurement for the number of rejected patients shows that with a certainty of 95% we can say that the true mean of the percentage of rejected patients lies between 0.15% patients and 0.35%. This means that the true mean of rejected patients lies between approximately 6 and 14 patients per year. The mean for the average number of transported patients lies between 20.46% and 22.60%, which is means it lies between approximately 840 and 920 patients per year. A graphical presentation of the CI's are shown in Figure 5.1.

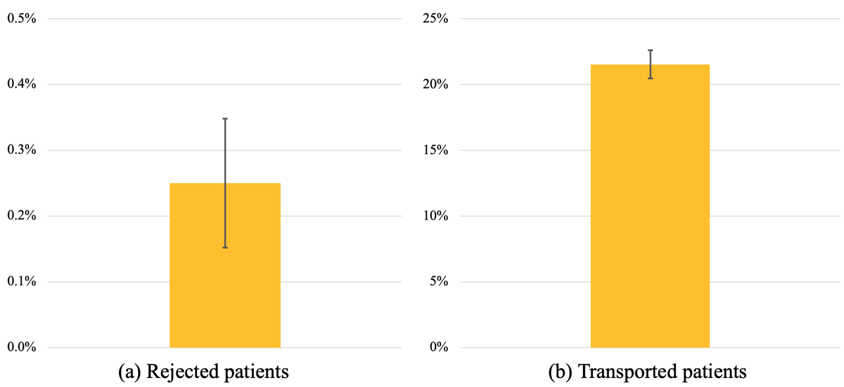


Figure 5.1: Baseline measurement of the number of rejected patients as a percentage of the total number of patients and the number of transported patients as a percentage of the total number of incoming patients. The error bars represent the 95%-CI of the true mean of the KPI. (n=82200 incoming patients)

5.2 N-to-all cross-training policy

Figure 5.2 presents the results for the number of rejected patients as a percentage of the total number of incoming patients for all experiments run with the n-to-all cross-training policy as well as the results for the baseline measurement. In the experiments, the number of participating nurses are varied as shown on the horizontal axis. The different colours in the figure represent the number of participating locations as these are varied as well.

What can be seen in the figure is that the number of rejected patients is relatively stable when introducing various configurations of the flex pool. All CIs lie between 0.28% and 0.38%, which is roughly 4 to 15 rejected patients per year. This interval is similar to what we see in the baseline measurement, where the average number of rejected patients per year lies between 6 and 14. This result is not surprising, as the total nursing capacity is not increased or decreased when introducing a flex pool. There are small differences between the percentage of rejected patients when the number of participating nurses increases, but the data does not show a pattern and the differences are not significant. Furthermore, varying the number of participating locations also does not have a significant effect on the number of rejected patients.

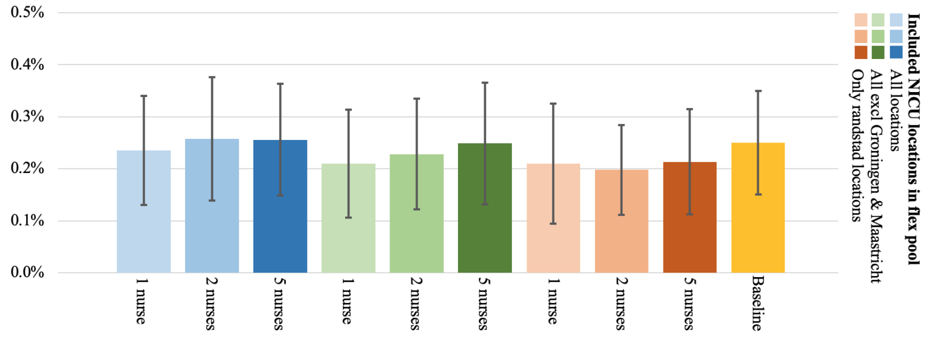


Figure 5.2: N-to-all cross-training policy - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200 incoming patients, 0.1% equals approximately 4 rejected patients per year)

The next KPI is the number of transported patients as a percentage of the total incoming patients, which are shown in Figure 5.3. The number of transported patients decreases as the number of participating nurses increases from one nurse to two nurses, but increasing the number of nurses from two to five does not make a significant difference. Increasing the number of participating nurses results in more capacity that can be moved when demand requires it, which explains why it results in less patient transport. It is surprising that this effect is not as present when the number is increased to five participating nurses, but this is attributed to the maximum number of beds at NICU locations. When these are fully occupied, the patient must be transported regardless of the availability of flex nurses. The results also show that the number of transported patients increases as the number of participating locations decreases, which is as expected as less participating locations result in less flexibility in the system.

The figure shows that introducing a flex pool with the n-to-all policy significantly reduces the number of patient transports. In the baseline measurement the average number of transported patients lies between 840 and 920 per year. The best performing experiment with the n-to-all policy (dark blue) shows that the average percentage of transported patients lies between 5.63% and 6.98%, which means the average number of transported patients lies between approximately 230 and 280. This is a reduction in the number of transported patients of approximately 70%. The worst performing experiment in terms of patient transport has an average percentage between 15.39% and 17.13%, which means patient transport is still reduced by approximately 25% compared to the baseline measurement.

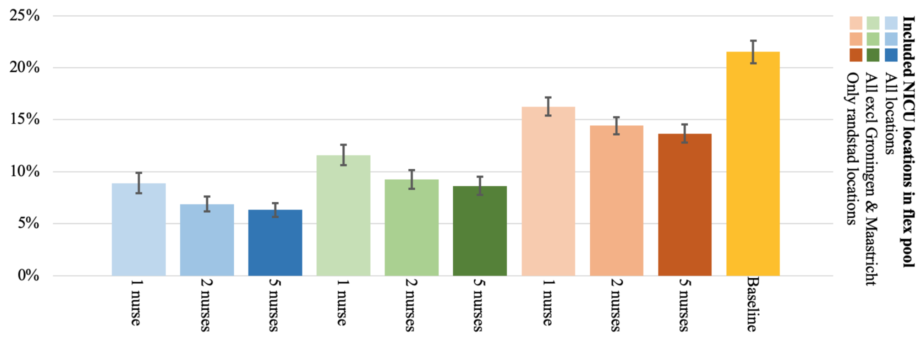


Figure 5.3: N-to-all cross-training policy - Number of transported patients as a percentage of the total number of incoming patients (n = 82200 incoming patients, 10% equals approximately 400 transported patients per year)

Figure 5.4 shows the number of nurse transfers as a percentage of the total number of nurse shifts for the n-to-all cross-training policy. As expected, the figure shows that the number of participating locations has an effect on the number of nurse transfers. When less locations participate, we see that the number of nurse transfers also decreases. What is interesting to note about this figure is that the number of participating nurses has a limited effect on the number of nurse transfers even though the number of patient transport decreases. A reason for this is that moving one nurse can prevent the movement of more than one patient. So, when the system has more flexibility due to more participating nurses, it can more efficiently assign nurses to locations.

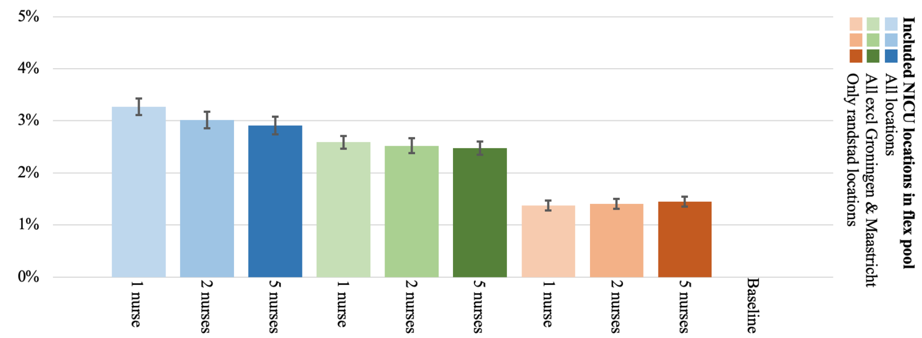


Figure 5.4: N-to-all cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all nurses (n = 1,714,216 shifts, 1% equals approximately 8500 nurse transfers per year)

The number of nurse transfers can also be expressed as a percentage of the total number of shifts of all flex nurses, as is shown in Figure 5.5. The figure shows that the percentage decreases as the number of nurses increases, which is as expected as the transfers can be divided among more nurses. The figure shows that the number of participating locations does not influence the percentage of nurse exchanges. For all experiments, the data shows that flex nurses are transferred 30% of their shifts when one nurse participates in the flex pool per location. This percentage drops significantly when two nurses are included per location, as it then amounts to approximately 15%. Also the percentages when five nurses are included are similar when including or excluding locations, as this is roughly equal to 5%.

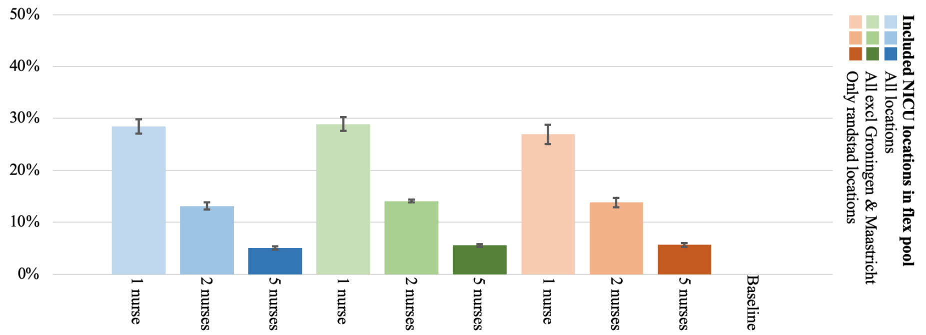


Figure 5.5: N-to-all cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all flex nurses (n = 197,100 shifts, 1% equals approximately 980 nurse transfers per year)

Figure 5.6 gives an overview of the number of times NICUs have received or provided a flex nurse as a percentage of the total number of exchanges in the model for the configuration where five nurses participate in the flex pool per location and where all locations participate. This gives an impression of the exchanges between NICU locations in the n-to-all policy. From the figure, we conclude that the flex pool is mainly used by larger NICU locations and locations that are centrally located. Locations that are less central, such as Groningen and Maastricht, only receive and provide a limited amount of nurses.

The figure shows that the locations that receive the most flex nurses (Figure 5.6a) are Amsterdam (22.79%), Rotterdam (22.85%), and Utrecht (13.88%). These are the three largest NICUs in the Netherlands and they are all centrally located. The location that provide the most flex nurses (Figure 5.6b) are Leiden (19.35%), Utrecht (18.80%), and Zwolle (14.18%). These locations are also quite central.

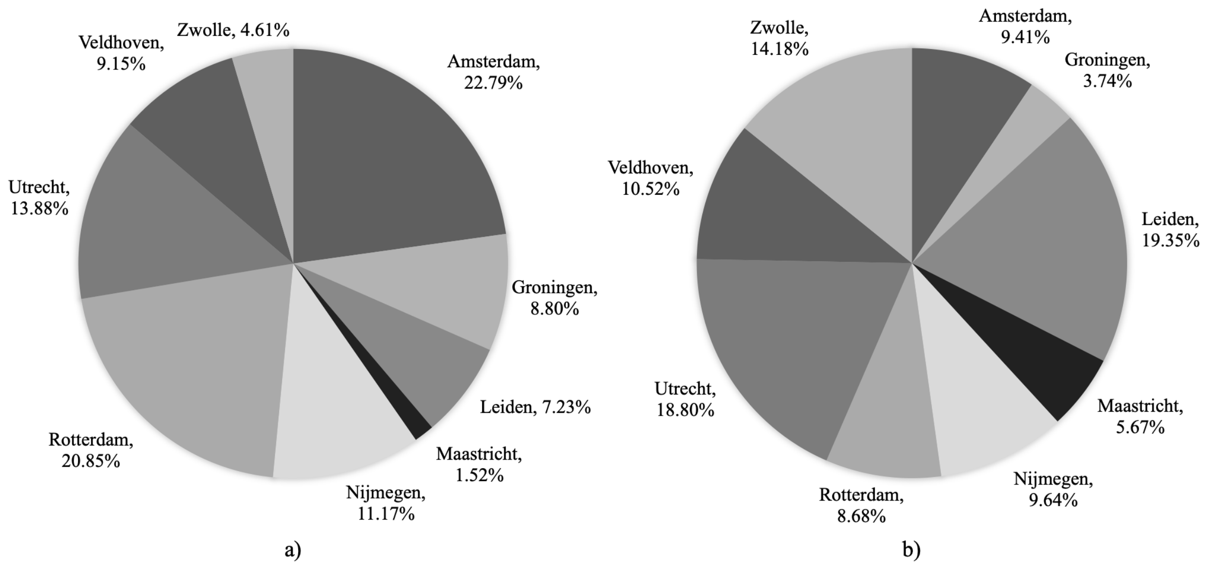


Figure 5.6: Pie chart on the exchanges between NICU locations in experiment with five particpating nurses, all locations included, and the n-to-all policy. a) shows the number of received flex nurses at each NICU location as a percentage of the total nurse exchanges and b) shows the number of provided flex nurses at each location as a percentage of the total nurse exchanges

5.3 Reciprocal pairs cross-training policy

Figure 5.7 shows the results for the number of rejected patients as a percentage of the total number of incoming patients for the reciprocal pairs training policy. Similar to the results for the n-to-all policy, the percentage of rejected patients is not affected by the number of participating nurses or the number of participating locations. The average percentage of rejected patients does not significantly differ between experiments. The CI for the mean percentage for all experiments is is between 0.06% and 0.33%, which is between approximately 3 and 13 patients per year. This is slightly lower than the CI for the baseline measurement, but this difference is not significant.

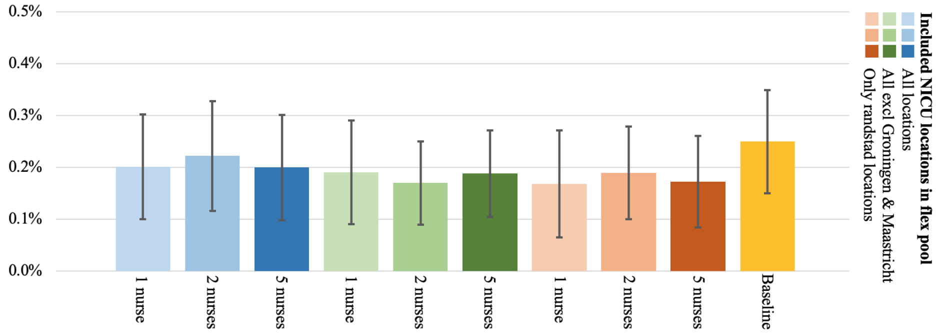


Figure 5.7: Reciprocal pairs cross-training policy - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200 incoming patients, 0.1% equals approximately 4 rejected patients per year)

When looking at the percentage of transported patients, as depicted in Figure 5.8, we see that the percentages of patient transports for the reciprocal pairs policy are somewhat higher than in the previous experiments. The results for the configurations with all locations (blue) and the configurations with all locations except Groningen and Maastricht (green) are compatible, which is surprising. When all locations are included in the flex pool, the average number of transported patients per year is between 480 and 650. When all locations are included except Groningen and Maastricht, the average number of transported patients per year is between 510 and 680. This is approximately a 35% decrease compared to the number of patient transport in the baseline measurement. When only the randstad locations are included (red), the percentage of patient transport is somewhat higher and amounts to an average amount yearly patient transport between 650 and 790 patients which is a decrease of roughly 15%.

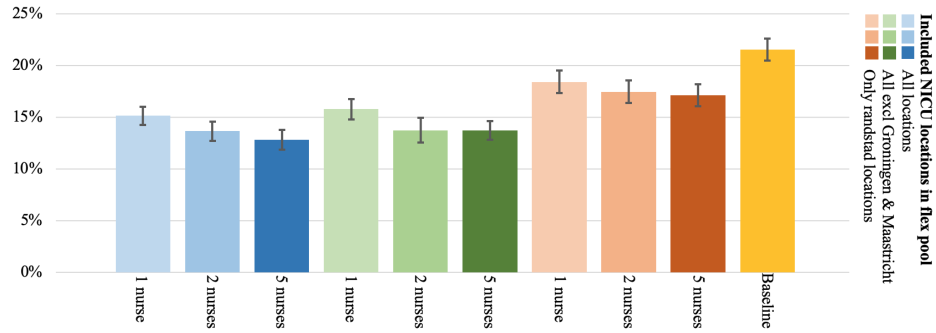


Figure 5.8: Reciprocal pairs cross-training policy - Number of transported patients as a percentage of the total number of incoming patients (n = 82200 incoming patients, 10% equals approximately 400 transported patients per year)

The results on the number of transferred nurses as a percentage of the total number of nurse shifts are shown in Figure 5.9. The number of participating nurses per location has a limited effect on the percentage of nurse transfers. Similar to the percentage of transported patients, we see that the percentages of transferred nurses when including all locations (blue) and when including all locations except Groningen and Maastricht (green) are rather similar. When only including randstad locations, we see that the number of transferred nurses is significantly lower.

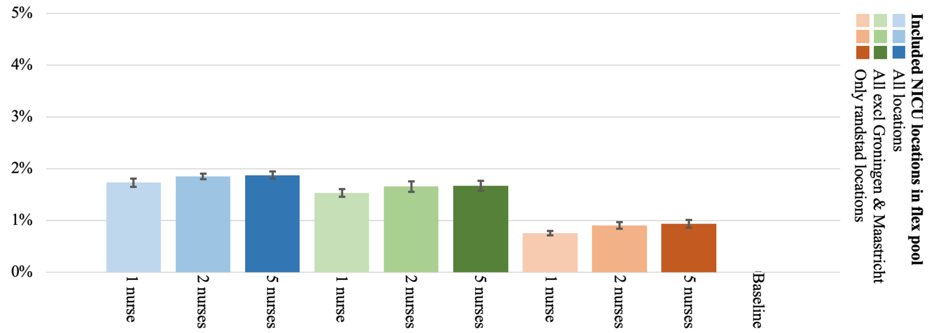


Figure 5.9: Reciprocal pairs cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all nurses (n = 1,714,216 shifts, 1% equals approximately 8500 nurse transfers per year))

The results on the number of nurse transfers as a percentage of the total number of flex nurse shifts, see Figure 5.10, show the same pattern when including or excluding certain locations. When one nurse per location participates in the pool, they will be working at external locations approximately 15% of the time. The percentage decreases as more nurses enter the pool. The percentage for the configurations including all locations except Groningen and Maastricht (green) is slightly higher than the configurations including all locations (blue). This is because we have seen in Figure 5.9 that patient transports is similar due to the use of flex nurses. As this has to be attained by using less flex nurses, the percentage for nurse transfers in the configurations including all locations except Groningen and Maastricht (green) is slightly higher than the configurations including all locations (blue).

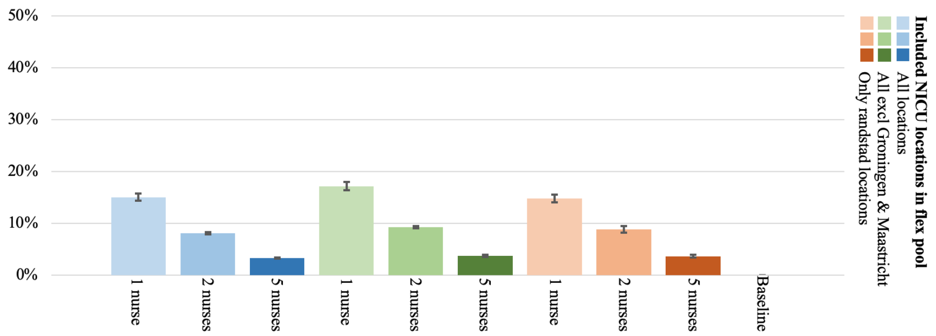


Figure 5.10: Reciprocal pairs cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all flex nurses (1% equals approximately 980 nurse transfers per year)

5.4 Chaining cross-training policy

Figure 5.11 shows the number of rejected patients as a percentage of the total incoming patients for the chaining cross-training policy. The data shows similar results as what is seen for the other cross-training policies, which is that the flex pool does not significantly impact the number of rejected patients. The average rejected number of patients in the experiments approximately lies between 3 and twelve per year, which is similar to the number seen in the baseline measurement.

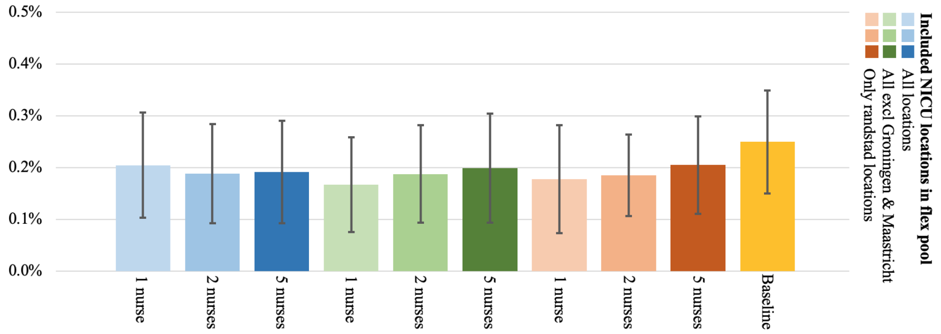


Figure 5.11: Chaining cross-training policy - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200, 0.1% equals approximately 4 rejected patients per year)

The analysis for the percentage of transported patients in the chaining policy, as shown in Figure 5.12, is similar to the analysis of the reciprocal pairs policy. We see that the number of transported patients decreases as the number of participating locations and nurses increases. Again, we see that the configurations in which all locations are included (blue) are similar to the configurations in which all locations are included except for Groningen and Maastricht (green). However, we also see that the difference between these two configurations and the configurations in which only the randstad locations are included (red) is smaller than in other cross-training policies.

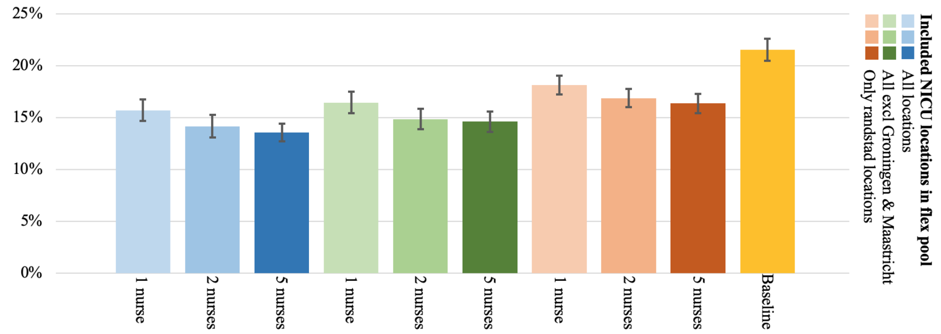


Figure 5.12: Chaining cross-training policy - Number of transported patients as a percentage of the total number of incoming patients (n = 82200, 10% equals approximately 400 transported patients per year))

Also the number of transferred nurses as a percentage of the total number of shifts of all nurses, see Figure 5.13, in the chaining policy is similar to the one in the previous cross-training policy. There is a pattern that indicates that the number of transferred nurses increases with the number of participating nurses and locations. This result is as would be expected.

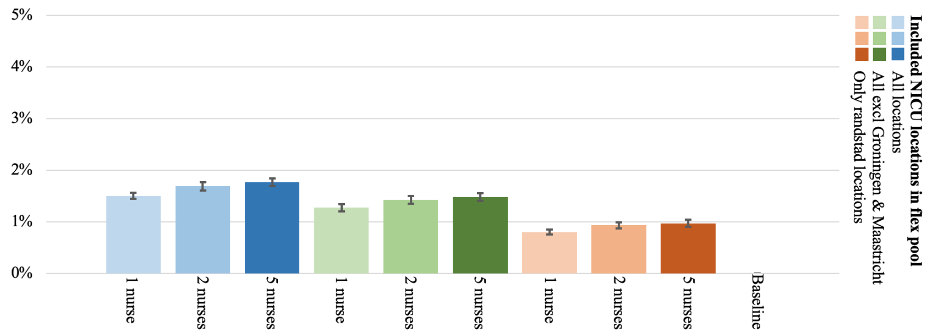


Figure 5.13: Chaining cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all nurses (n = 1,714,216 shifts, 1% equals approximately 8500 nurse transfers per year))

Finally, the number of transferred nurses as a percentage of the total number of shifts of all flex nurses, see Figure 5.14 also shows similarities with previous policies. Again, the percentage is slightly higher for the configurations in which all locations are included except Groningen and Maastricht (green) compared to the configurations in which all locations are included (blue). This is caused by the fact that the number of patient transfers is similar but this has to be attained with less flex nurses in the flex pool.

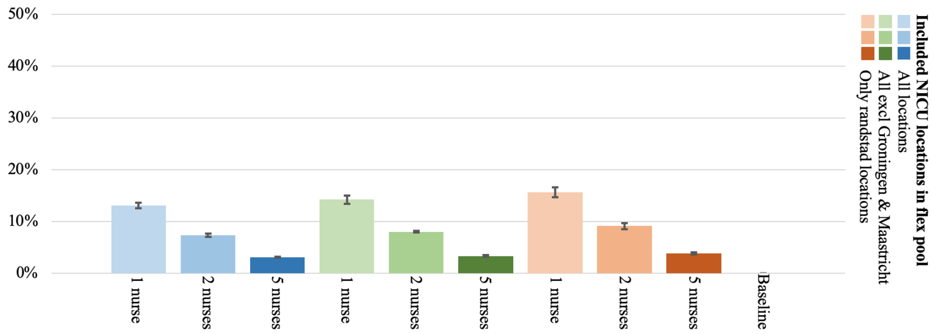


Figure 5.14: Chaining cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all nurses (1% equals approximately 980 nurse transfers per year)

As mentioned, the chain identified can be followed clockwise or counterclockwise. Appendix E shows the data for the reversed tour. When reversing the route of the chaining policy, we see that there are no significant differences in the percentage of rejected patients and the percentage of transported patients compared to the route presented above. This is why we will not consider the reversed route in the remainder of this research.

5.5 Comparison cross-training policies

When comparing the effects of the different cross-training policies, several conclusions can be made. First, the cross-training policy n-to-all provides the most reduction in the number of patient transports as a percentage of the total incoming patients for each identified experiment. Furthermore, the reciprocal pairs policy and the chaining policy only show a slight significant difference when looking at the percentage of rejected patients. In the reciprocal pairs policy we see a slight decrease in the configurations where all locations are incorporated and where all locations except Groningen and Maastricht are incorporated.

In terms of the number of nurse transfers as a percentage of the total number of nurse shifts, we see that the n-to-all policy requires the most nurse transfers for each experiment. Again, these numbers are similar for the other two cross-training policies. This is expected, as both policies only allow for a limited number of locations to exchange nurses with. The difference between the two policies is that in reciprocal pairs, a NICU exchanges nurses with one other NICU and in the chaining policy, the NICUs form a chain and receive nurses from a different location than the location they send nurses to. Given this, the policy reciprocal pairs might be preferred if the results are similar, as this could lead to more familiarity between nurses. When comparing the nurse transfers with only the total number of shifts of flex nurses, we also see that the n-to-all policy requires more transfers.

There are slight differences between the percentage of rejected patients in the various training policies, but these differences are not significant.

5.6 Sensitivity analysis

A sensitivity analysis is done on the input parameters of the two most promising experiments, as shown in Table 5.1. The first experiment that is chosen for the sensitivity analysis is the experiment that resulted in the lowest percentage of patient transport. The configurations for this experiment were five participating nurses per location, the participation of all locations, and the n-to-all cross-training policy. These configurations allow for an approximate reduction in patient transport of 70%, which is approximately 230-280 patient transports per year compared to 840-920 patient transports per year in the baseline measurement.

The second experiment included in the sensitivity analysis is the experiment with 2 participating nurses for each location, the inclusion all locations except for Groningen and Maastricht, and the reciprocal pairs policy. The reason this experiment is selected is because the results are promising in terms of the number of transported patients as a percentage of the total incoming patients as it shows an approximate reduction in transports of 35%, which is roughly 510-600 patient transports per year compared to 840-920 patient transports per year in the baseline measurement. More importantly, this experiment is interesting as this cross-training policy might be more inviting to NICU nurses. The reciprocal pairs cross-training policy limits the number of locations a nurse has to be familiar with and also sets a boundary on the travel time for nurses. Furthermore, we decided to include two participating nurses as this configuration performed better than one nurse but not worse than five nurses. So, including two nurses will result in the same reduction in patient transports without unnecessarily increasing the complexity of the flex pool.

Table 5.1: Configurations of experiments considered in the sensitivity analysis

Configuration	**Experiment 1**	**Experiment 2**
Number of participating nurses	5	2
Participating locations	All locations	All excl. Groningen and Maastricht
Cross-training policy	N-to-all	Reciprocal pairs

The sensitivity analysis on the number of patients are shown in Figures 5.15, 5.16, and 5.17. The figures show that when the number of patients increases with 10%, the number of rejected patients and the number of transported patients increase as well. However, compared to the baseline measurement, this still results in a reduction of approximately 60% for the number of transported patients for experiment 1, which is on average 500 patients per year compared to 1200 per year. In experiment 2, the results show an approximate reduction in the number of transported patients of 25% in experiment 2, which equals roughly 900 transported patients instead of 1200. When the average value for the number of patients was used, the reduction for experiment 1 was 70% and 35% for experiment 2.

Similar to the results of the experiments, we see that there is no significant difference between the percentage of rejected patients of the baseline measurement and the experiments. The percentage of nurse transfers also increases as the number of patients increases. The sensitivity analysis shows that using the flex pool of nurses also results in less patient transport when the number of patients are increased or decreased by 10%. In percentages, these are similar to what we see when increasing these parameters.

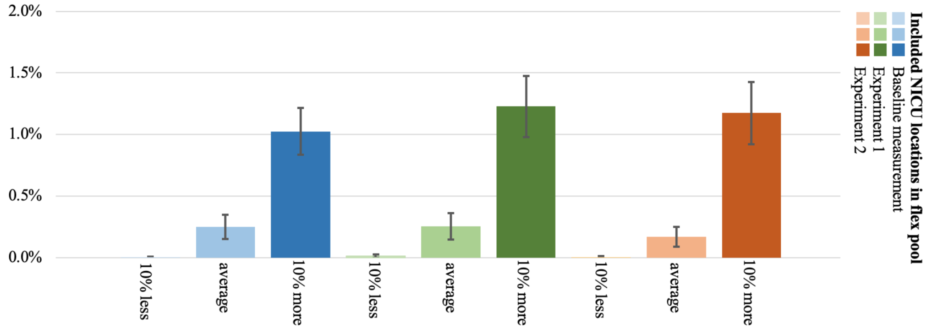


Figure 5.15: Sensitivity analysis on number of patients - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200 incoming patients +/- 10%)

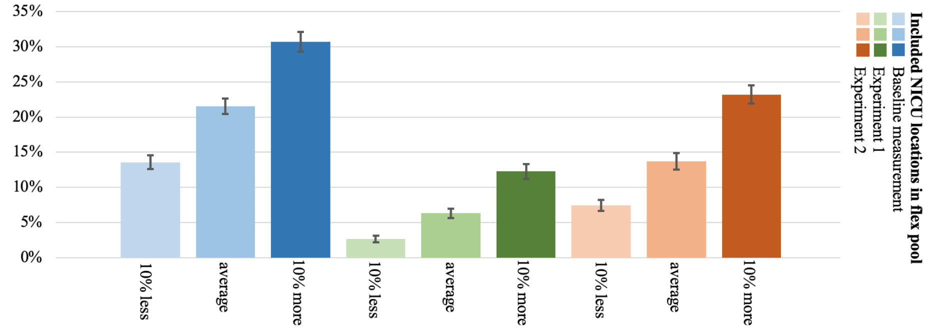


Figure 5.16: Sensitivity analysis on number of patients - Number of transported patients as a percentage of the total number of incoming patients (n = 82200 incoming patients +/- 10%)

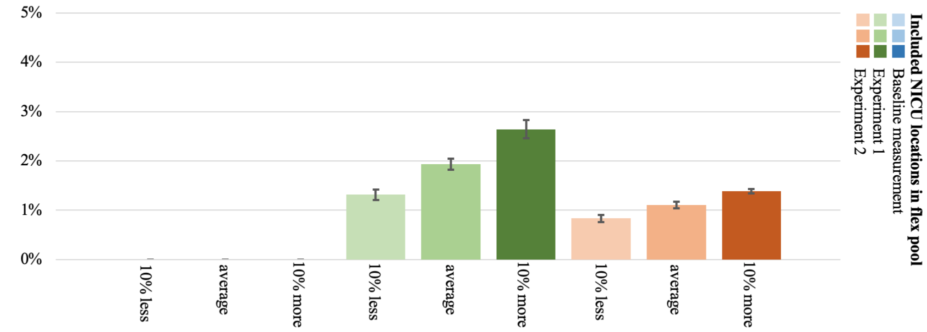


Figure 5.17: Sensitivity analysis on number of patients - Number of shifts in which a nurse is transferred as a percentage of the total number of shifts of all nurses (1% equals approximately 980 nurse transfers per year)

The sensitivity analysis on the LOS of patients shows similar results as the sensitivity analysis on the number of patients. This is expected, as in both instances, the input parameter is decreased by 10% and increased by 10%. The results of the sensitivity analysis on the LOS of patients are shown in Figures 5.18, 5.19, and 5.20. The impact of increasing the LOS in terms of patient transport is similar to the percentages seen in the sensitivity analysis on the number of patients. For experiment 1, this results in a reduction of approximately 60% and for 25% in experiment 2.

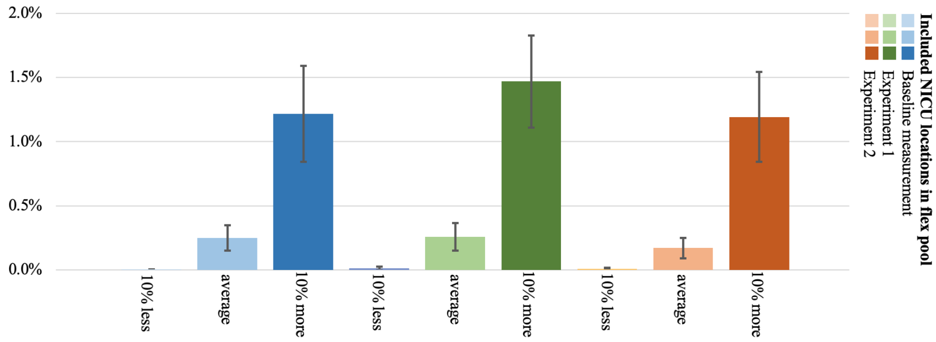


Figure 5.18: Sensitivity analysis on LOS of patients - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200 incoming patients)

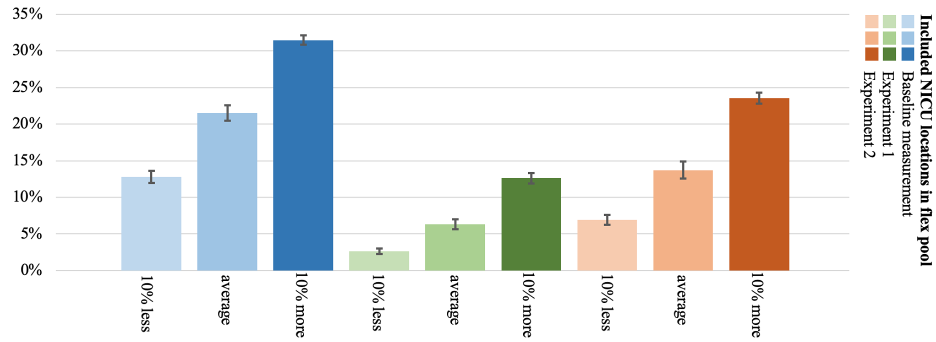


Figure 5.19: Sensitivity analysis on LOS of patients - Number of transported patients as a percentage of the total number of incoming patients (n = 82200 incoming patients)

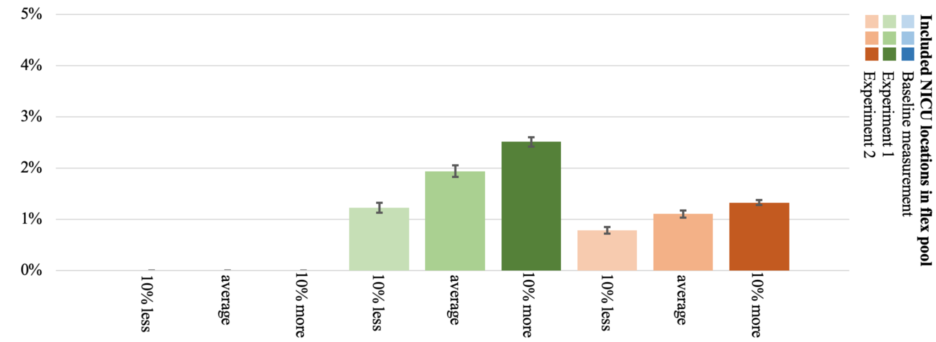


Figure 5.20: Sensitivity analysis on LOS of patients - Number of shifts in which a nurse is transferred as a percentage of the total number of shifts of all nurses (1% equals approximately 980 nurse transfers per year)

The final sensitivity analysis focuses on the acuity of patients. As previously mentioned, we have chosen to use a patient acuity distribution in the experiments that is based on an analysis done at WKZ. Literature shows that in critical care, the nurse-to-patient ratio is equal to one nurse per two patients. Even though the distribution used has an average acuity of approximately 0.5 per patient, it is interesting to perform an analysis in which all patients have the same acuity. The results for the analysis are shown in Figures 5.21, 5.22, and 5.23.

The results show that changing the acuity of patients to 0.5 does not have a big effect on the KPIs. The number of rejects does not show a significant difference. The number of patient transports as a percentage of the total number of incoming patients shows a slight difference. Interestingly, this difference is significant for the baseline measurement but not for the experiments. This shows that using the flex pool results in more efficient allocation of patients, which is why the difference is not noticeable in the experiments. The number of nurse transfers as a percentage of the total number of nurse shifts also decreases.

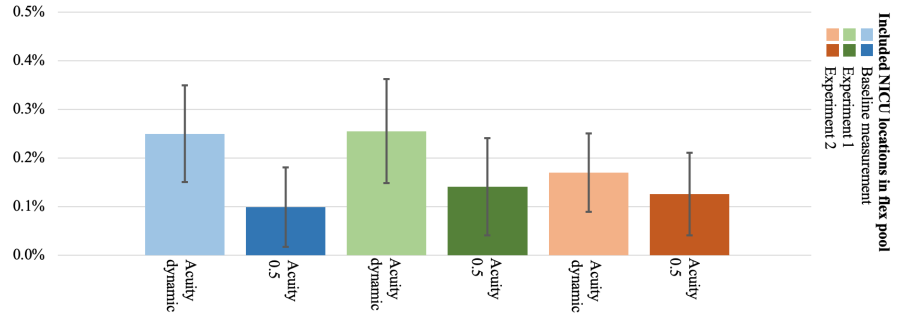


Figure 5.21: Sensitivity analysis on patient acuity - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200 incoming patients)

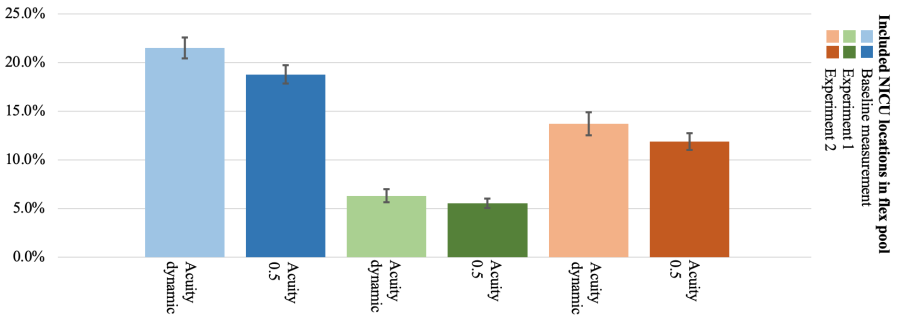


Figure 5.22: Sensitivity analysis on patient acuity - Number of transported patients as a percentage of the total number of incoming patients (n = 82200 incoming patients)

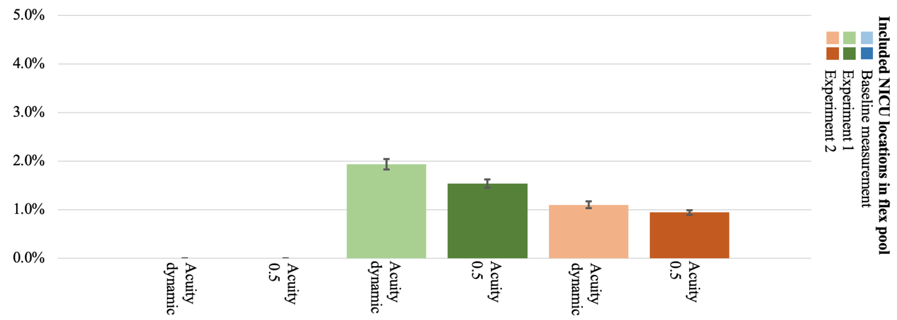


Figure 5.23: Sensitivity analysis on patient acuity - Number of shifts in which a nurse is transferred as a percentage of the total number of shifts of all nurses (1% equals approximately 980 nurse transfers per year)

The overall sensitivity analysis shows that the flex pool for nurses does not loose its effectiveness when the number of patients, the LOS of patients, or the acuity of patients varies. When these parameters decrease, we see that the flex pool outperforms the model without the flex nurses in terms of patient transports. This means that even if the capacity constraints surrounding the NICUs becomes less critical, the implementation of the flex pool still results in less patient transports. Furthermore, when the number of patients is increased by 10%, we still see that the flex pool outperforms the model without the flex pool. For the configuration with five participating nurses, inclusion of all locations, and the n-to-all policy this results in an approximate reduction of 60% compared to the 70% reduction we see when using the average values for the input parameters. For the configuration with two participating nurses, inclusion of all locations except Groningen and Maastricht, and the reciprocal pairs policy this results in a reduction of approximately 25% compared to the previous 35%. So, if the number of patients or the LOS of patients increases in the coming years or if we have underestimated the parameters, the flex pool will still reduce the number of patient transports.

5.7 Conclusion

This chapter answered the final research question "*What are the effects of different policies concerning the flex pool of nurses on the number of patient transfers and the number of nurse exchanges?*"

The experiments with the flex pool of nurses show that its implementation significantly reduces patient transport. The experimental factors number of participating nurses and number of participating locations are both negatively correlated with the number of patient transports. Furthermore, we see that the number of nurse transfers is positively correlated with these experimental factors.

The cross-training policy n-to-all results in the lowest possible patient transport, but requires nurses to work at many locations. The other cross-training policies require less effort from nurses, but also result in less reduction in patient transport. There are no significant differences between these cross-training policies in terms of patient rejection or transport.

The most promising configuration in terms of the percentage of transported patients is when five nurses per location participate in the flex pool, when all locations are included, and when the n-to-all policy is used. This results in an approximate reduction in patient transport of 70%, which is approximately 230-280 patient transports per year compared to 840-920 patient transports per year in the baseline measurement. However, this policy requires nurses to work at many locations and increases the organisational complexity of the flex pool.

For this reason, the configuration in which two nurses per location participate in the flex pool, when all locations are included except Groningen and Maastricht, and when the reciprocal pairs policy is used might be more interesting. This policy allows an approximate reduction in transports of 35%, which is roughly 510-600 patient transports per year. The benefits are that nurses only have to be trained for two NICU locations and the number of shifts in which flex nurses are transferred is lower.

The sensitivity analysis on various input parameters show that the model still outperforms the baseline measurement when input parameters are increased or decreased. The results show that the flex pool still results in less patient transport in case the number of patients of the LOS of patients increases. When these numbers are lower, the baseline measurements shows a lower percentage of patient transports, but also in this instance the flex pool outperforms the baseline measurement.

6 CONCLUSION

6.1 Conclusion

This project was undertaken to design and evaluate the effects of a flex pool of nurses in the Dutch neonatal network. The motivation for this research stems from the need to reduce patient transport in the Netherlands. We are the first to to analyse how pooling nursing capacity leads to a decrease in patient transport in a neonatal network by introducing a flex pool of nurses. Therefore, this research has contributed to theory by formulating rules that allow for the implementation of such a system. We have analysed the flex pool by creating a discrete event simulation model. Furthermore, an integer linear problem is incorporated in the model to assign flex nurses and patients to NICU locations.

The model allows for experimentation with different configurations. These configurations are focused on varying the number of participating nurses, the number of participating locations, and varying cross-training policies. The model can easily be adapted to fit other (health care) networks as the input parameters can be adjusted to other environments. So besides the Dutch neonatal network, the model can also be used to investigate the implementation of a flex pool of nurses in the same hospital or between general hospitals.

The analysis shows that the a flex pool of nurses results in a significant reduction in the number of patient transports. The results are analysed by looking at the number of rejected patients, the number of transported patients, and the number of transferred nurses. We conclude that the number of participating nurses and locations is negatively correlated with the number of patient transports and positively correlated with the number of nurse transfers.

When aiming for the largest reduction in patient transport, we recommend to include five participating nurses per location in the flex pool, to include all locations, and to use the n-to-all cross-training policy. The results show that this can reduce the number of patient transport by approximately 70%. In the baseline measurement, the number of patient transports lies between 840 and 920 per year. Following these configurations, the number of patient transport can be decreased to approximately 230 to 280 patients per year.

However, considering the magnitude of change that the implementation of the flex pool will have on the Dutch neonatal network, we recommend to limit the organisational complexity of the flex pool. When two participating nurses are included in the pool, when all locations are included except Groningen and Maastricht, and when the reciprocal pairs policy is chosen, we can still reduce the amount of patient transport by 35%. These configurations will require less effort from NICU nurses and create more familiarity between NICU locations. The average number of patient transports in this scenario will be between 510 and 680 patients per year. After successful implementation of these configurations, the flex pool can be gradually expanded to include more locations and more participating nurses.

The results of the research provide quantitative data on the improvement potential of introducing a flex pool of nurses in the Dutch neonatal network. Neonatologists in the Netherlands have been trying for years to decrease the number of patient transports and this we provide a quantitative basis to support the discussion on whether a flex pool of nurses should be implemented.

6.2 Limitations

The research presented in this thesis is subject to several limitations, most of which are centered around a lack of data or uncertainty in the data regarding patients or nursing capacity. Even though the sensitivity analysis has shown that increasing or decreasing certain parameters still results in significantly less patient transport when the flex pool is used compared to when the flex pool is not used, it is important to mention uncertainties in the data.

Neonatologists and nurses experience two busy periods at NICUs: the summer period and the winter period. In the summer, personnel goes on holiday, which puts a strain on the nursing capacity. In the winter, there is an increase in the number of patients caused by the RS-virus. We have not been able to include these busy periods in the model as there is no data on this. However, this could affect the usefulness of the flex pool of nurses. The logbook of BZB can provide useful information on these patterns, but at the time of writing this thesis only the data of 2020 is available.

Another limitation concerns the assumptions made for the operational capacity of NICU locations. The operational capacity used in the model is estimated by means of real data gathered by the WKZ on the number of operational beds at all NICUs. However, as this data only contained a small sample size, caution must be applied, as these findings might not reflect the actual operational capacity of NICU locations. Also, this data was rather limited and was focused on the number of operational beds even though the data was used to estimate the number of available nurses. Moreover, a source of uncertainty is caused by a lack of data concerning the distribution of patient acuity. For this reason, a distribution was used that of previous research at the WKZ. On average, the data reflects the patient acuity seen at the WKZ, but more measurements could result in more validity for this input parameter.

Moreover, as discussed in Chapter 2, we have not included specialised treatments in the model. This affects the outcomes of our research, as including this in the model would mean that the number of patient transports cannot be reduced to zero. Furthermore, if a patient's primary NICU does provide the specialised care required but is fully occupied, the patient has to be transported even further. At the time of writing this thesis, the data on the percentages of patients that require the specialised care types is unknown, which is why this was not included in the analysis. However, we have included the option to incorporate this in the model. So once the data has been gathered, the percentages can be easily filled in.

Finally, it can be argued that the positive results regarding the decrease in patient transport in this research were due to the methods used for analysis. In real-life, it frequently happens that there is not enough capacity to admit an additional patient, but that the patient is placed in an emergency bed nonetheless. Using these beds is not preferred and not a long-term solution, as this results in lower nurse-to-patient ratios and increases the workload for nurses. In the model, this may have caused the number of patient transports to be higher than experienced in practice. For this reason, the model has been validated by neonatologists from three different NICU locations, who concluded that the model sufficiently represents the Dutch neonatal network to examine the flex pool with. Despite this, it must be noted that this could cause the possible decrease in patient transport to be higher in the model than in reality as there is more patient transport to be decreased in the model.

6.3 Further research

Our model can be used to perform additional analyses on the capacity allocation in the Dutch neonatal network. When the model is run without including any nurses in the flex pool, we can deduct the number of times NICUs have to reject patients from their own catchment area. This can be used to evaluate the current capacity assignment and to investigate different ways to allocate NICU capacity. This can be done with or without including flex nurses in the system. For a more accurate analysis of this, an analytical model can be created that investigates the pooling effects by means of a queuing network. This would allow for calculations that are not based on a heuristic approach.

Furthermore, reserving capacity for patients of a NICUs own catchment area might also result in less patient transport. If NICU locations reserve beds for possible patients of their own catchment area, the overall number of transported patients may decrease. It would be interesting to investigate whether the combination of reserving beds and implementing a flex pool of nurses could lead to even less patient transport. A further study with more focus on the admission policies of NICUs is therefore suggested.

Finally, there is abundant room for further research in determining the different barriers to implementing a flex pool of nurses. Amongst others, these include financial, ethical and legal barriers, each of which should be explored. Many questions regarding the willingness of nurses to participate in such a pool remain unanswered as this was not part of the aim of this research. However, without participation of nurses, the system cannot be executed. It is of great importance to find out whether hospital staff would be eager to participate and what benefits should be offered to them to convince them.

Despite the numerous barriers regarding the implementation of a flex pool of nurses, it must be mentioned that there are success stories of hospitals that cooperate by sharing nurses. An excellent example of this is the Fertiliteits Kliniek Twente (Twente, 2021), which started as an initiative of gynaecologists from the hospital Medisch Spectrum Twente and the hospital Ziekenhuis Groep Twente. Furthermore, the various locations of the St. Antonius Ziekenhuis have started a pilot where they share their emergency transportation personnel (Booij, 2021). Also the Amphia Ziekenhuis, the Bravis Ziekenhuis, Bernhoven, the Catharina Ziekenhuis, Elkerliek, the Elisabeth-TweeSteden Ziekenhuis, the Jeroen Bosch Ziekenhuis, the Máxima MC and the St. Anna Ziekenhuis are planning on implementing a system similar to the flex pool of nurses for their emergency department personnel (van Beers, 2021). These examples show that there is a willingness amongst different personnel types to participate in out of the box ideas and if hospitals work together, we believe that they can overcome the barriers they may face. These exchanges will also allow hospitals to benchmark their practices to the practices of other hospitals. By learning about the organisation and processes of other hospitals, participating hospitals might be able to organise their own care more efficiently.

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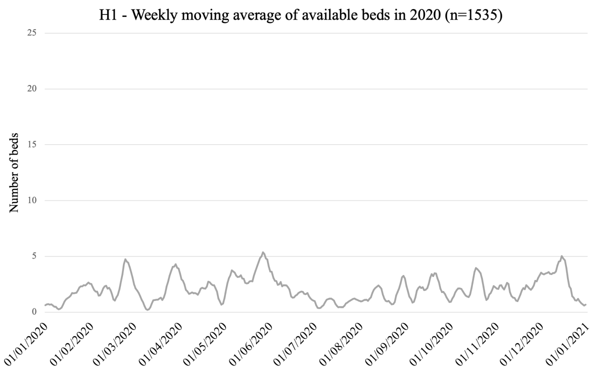
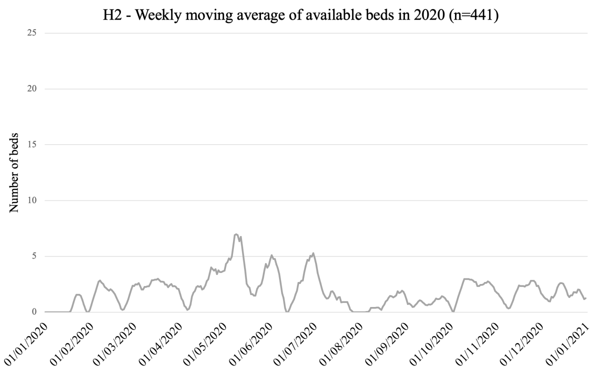
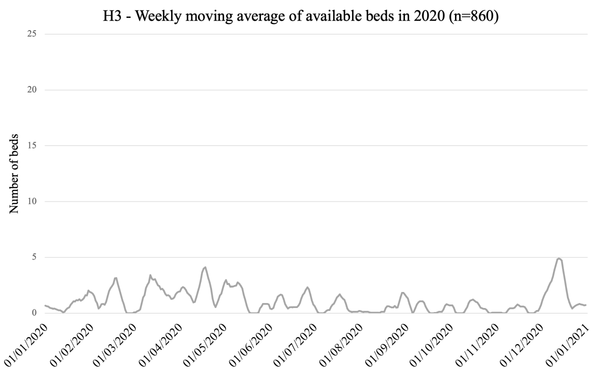
A MOVING AVERAGE AVAILABLE BEDS FOR INDIVIDUAL NICUS

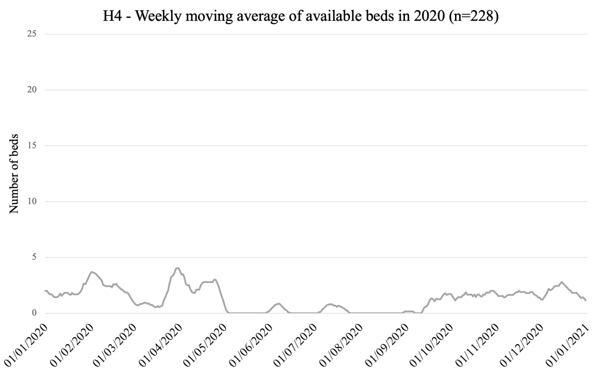
The figures below show the moving averages of the available number of beds for individual NICU locations. The names of the NICU locations are not mentioned with the pictures, as this is confidential information.

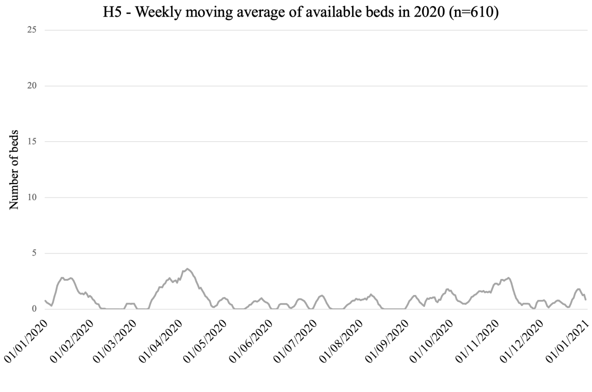
The figures show that all NICUs experience periods in which they have hardly any beds available. Furthermore, the figures also show that the number of available beds at a location rarely exceeds five. This allows us to conclude that there are no NICU locations with spare capacity.

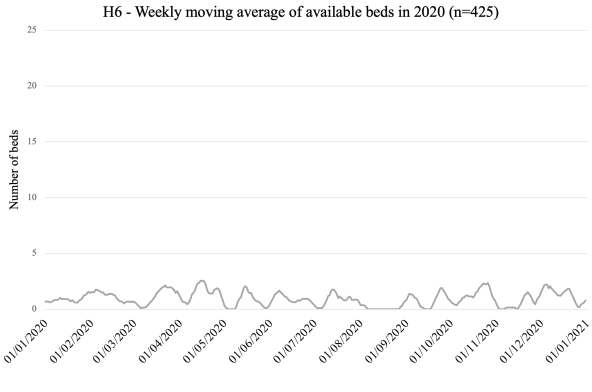


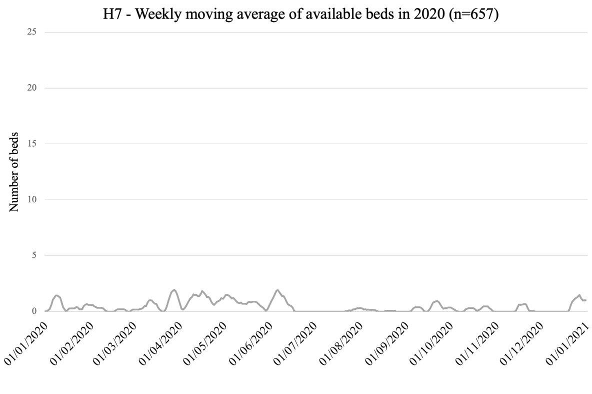


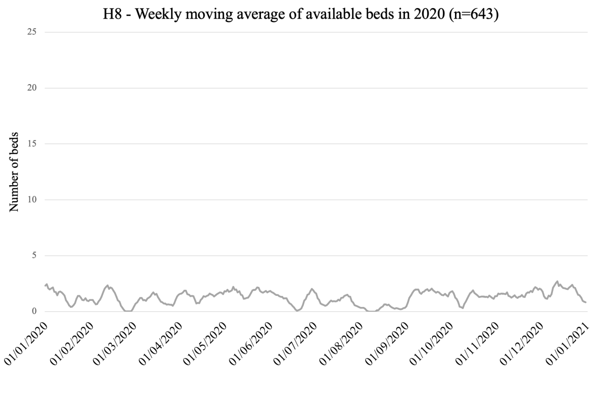





H5 - Weekly moving average of available beds in 2020 (n=610)
Number of beds
25
20
15
10
5
0
01/01/2020
01/02/2020
01/03/2020
01/04/2020
01/05/2020
01/06/2020
01/07/2020
01/08/2020
01/09/2020
01/10/2020
01/11/2020
01/12/2020
01/01/2021


H6 - Weekly moving average of available beds in 2020 (n=425)
Number of beds
25
20
15
10
5
0
01/01/2020
01/02/2020
01/03/2020
01/04/2020
01/05/2020
01/06/2020
01/07/2020
01/08/2020
01/09/2020
01/10/2020
01/11/2020
01/12/2020
01/01/2021


H7 - Weekly moving average of available beds in 2020 (n=657)
Number of beds
25
20
15
10
5
0
01/01/2020
01/02/2020
01/03/2020
01/04/2020
01/05/2020
01/06/2020
01/07/2020
01/08/2020
01/09/2020
01/10/2020
01/11/2020
01/12/2020
01/01/2021


H8 - Weekly moving average of available beds in 2020 (n=643)
Number of beds
25
20
15
10
5
0
01/01/2020
01/02/2020
01/03/2020
01/04/2020
01/05/2020
01/06/2020
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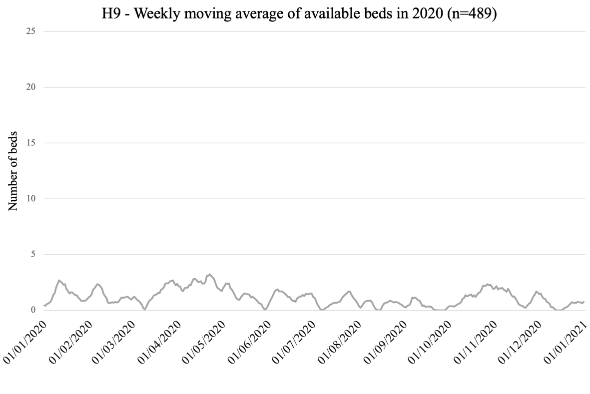
01/08/2020
01/09/2020
01/10/2020
01/11/2020
01/12/2020
01/01/2021


H9 - Weekly moving average of available beds in 2020 (n=489)
Number of beds
25
20
15
10
5
0
01/01/2020
01/02/2020
01/03/2020
01/04/2020
01/05/2020
01/06/2020
01/07/2020
01/08/2020
01/09/2020
01/10/2020
01/11/2020
01/12/2020
01/01/2021

B LITERATURE REVIEW ON NURSING SHORTAGE SOLUTIONS

To gather an overview of the possible solutions discussed in the literature regarding the nursing shortage faced by hospital, a literature review is performed. The database used for this literature review is the Scopus database, as provided by the University of Twente. Through this medium, an initial search was done to find relevant literature based on the title, keywords, and abstract. The search string used was:

("*nurse*" OR "*nursing*") AND ("*shortage*" OR "*shortages*") AND ("*staffing*" OR "*solutions*" OR "*"policies"*" OR "*strategies*")

In total, these keywords provided a collection of 107 sources from the Scopus library. The sources were then filtered based on several exclusion criteria. The texts should be written in Dutch or English. Furthermore, the source types were limited to articles, books, book chapters, and reviews. Moreover, sources were excluded if they were written before the year 2000 or if the full text was not available. Finally, a number of sources were excluded as an initial scan of the title and abstract showed that they discussed cases not relevant to this research. A graphical representation of the selection process of the systematic literature review can be found in table B.1. Table B.2 and table B.3 provide an overview of the different strategies discussed in the remaining twenty papers.

Key words	**Nr of sources**
Database Scopus ("nurse" OR "nursing") AND ("shortage" OR "shortages") AND ("staffing" OR "solution" OR "solutions" OR "policy" OR "strategies")	107
Exclusion criteria	
Written in language other than Dutch or English	-1
Limit to Article, Book, Book Chapter, or Review	-6
Pre-2000 articles	-11
Full article not available	-9
Discusses cases not relevant to this research	-60
Total number of sources selected for review	**20**

Table B.1: Overview of exclusion criteria for literature review on possible solutions for the staffing shortage

Source	Increase retainment efforts	Increase recruitment efforts	Improve benefits	Improve education infrastructure	Increase compensation
(Shamsi and Peyravi, 2020)	x		x		x
(McDonald et al., 2019)	x	x	x		
(Aboshaiqah, 2016)				x	
(Liu et al., 2013)			x	x	
(Seo and Spetz, 2013)					
(Adams, 2009)				x	
(Zarea et al., 2009)		x			x
(Hammer and Craig, 2008)	x	x			
(Colosi, 2007)	x	x			
(Westendorf, 2007)	x	x	x	x	x
(May et al., 2006)			x	x	x
(Inman et al., 2005)					
(Cohen et al., 2004)		x			
(Lambrinos et al., 2004)	x			x	x
(Hess Jr., 2004)			x		
(Janiszewski Goodin, 2003)	x	x			
(Rambur et al., 2003)	x		x	x	x
(Neuhauser, 2002)	x				
(Nevidjon and Erickson, 2001)	x	x			

Table B.2: A. Overview of the solutions to the nurse staffing shortage discussed in the papers resulting from the literature search

Source	Improve work environment	Promote public image of nursing	Employ temporary staff	Support legislation and policy	Improve job satisfaction
(Shamsi and Peyravi, 2020)	x	x			
(McDonald et al., 2019)			x		
(Aboshaiqah, 2016)	x	x			
(Liu et al., 2013)	x				
(Seo and Spetz, 2013)			x		
(Adams, 2009)					
(Zarea et al., 2009)	x	x			x
(Hammer and Craig, 2008)					
(Colosi, 2007)					
(Westendorf, 2007)					x
(May et al., 2006)		x	x		
(Inman et al., 2005)			x		
(Cohen et al., 2004)					
(Lambrinos et al., 2004)					
(Hess Jr., 2004)					
(Janiszewski Goodin, 2003)	x			x	
(Rambur et al., 2003)		x		x	
(Neuhauser, 2002)					
(Nevidjon and Erickson, 2001)	x			x	

Table B.3: B. Overview of the solutions to the nurse staffing shortage discussed in the papers resulting from the literature search

C LITERATURE REVIEW ON TEMPORARY STAFFING

Similar to the literature review on nursing shortage solutions, a literature review is also performed on the information surrounding the temporary staffing solution. Again, the database used is Scopus and the initial search was done based on the title, keywords, and abstract of papers. The search string used was:

(*"nursing float pools"* OR *"nursing float pool"* OR *"float pools"* OR *"float pool"* OR *"resource teams"* OR *"resource team"* OR *"temporary staff"* OR *"temporary staffing"* OR *"temporary nurses"* OR *"temporary employment nurses"* OR *"cross-trained nurses"*)

Key words	**Nr of sources**
Database Scopus *"nursing float pools"* OR *"nursing float pool"* OR *"float pools"* OR *"float pool"* OR *"resource teams"* OR *"resource team"* OR *"temporary staff"* OR *"temporary staffing"* OR *"temporary nurses"* OR *"temporary employment nurses"* OR *"cross-trained nurses"*	371
Exclusion criteria	
Written in language other than Dutch or English	-2
Limit to Article, Book, Book Chapter, or Review	-17
Pre-2000 articles	-36
Full article not available	-9
Discusses cases not relevant to this research	-277
Total number of sources selected for review	**30**

Table C.1: Overview of exclusion criteria for literature review on temporary staffing

In total, these keywords resulted in 371 sources. By following a similar process as used in the literature review on nursing shortages, we ended up with 30 usable and relevant articles. The other articles were rejected based on the language they were written in, their document type, publication date, availability, or their topic.

D EVENT TYPES IN SIMULATION MODEL

Patient attributes

The model starts by generating patients for each NICU location. The patients are given several attributes; a patient number, an arrival time, a service time, a primary NICU, an acuity, a required number of beds, and the required treatment type.

To model the arrival of patients, it is assumed that patients arrive according to a Poisson distribution with exponential arrival times. To calculate the arrival rate of patients at individual NICUs, the yearly arrival rate of patients is multiplied by the percentage of births in a NICU's catchment area as presented in 2.2. In addition to an arrival time, patients also have to be assigned a LOS. The assumption is made that the LOS of patients does not depend on the NICU location that treats them. Patients admitted to a NICU experience different levels of acuity and in the model patient acuity is assigned based on the distribution presented in Table 2.4.

The last patient characteristic is the number of required beds for a patient. In the Netherlands, there is a 1.6% chance that a pregnancy results in twins. In case of twins, we want to treat the patients in the same hospital. That is why we model a set of twins as one patient that requires two beds and where the patient acuity is multiplied by two.

Patient arrival

Each NICU location aims to treat as many patients of their own region as possible. In this way, patients are treated as close to home as possible. So, when a patient arrives in the system, the model starts by checking if the patient can be placed at their primary NICU. The verdict on whether or not this is possible, is dependent on the availability of beds and the availability of nurses. The availability of beds is determined by looking at the number of already admitted patients and the number of physical beds at the primary NICU. The availability of nurses is checked by calculating the cumulative acuity of the admitted patients and comparing this number with the number of nurses present at the NICU. If the cumulative acuity plus the new patient's acuity is lower than the number of present nurses, there is enough nursing capacity to admit an additional patient. In the model, patients are not moved from one NICU location to another.

If there is not enough capacity to admit an additional patient, the patient cannot immediately be placed at the primary NICU. In the model, it is assumed that the patient can then can be placed in a temporary bed at the primary NICU. The patient will then be assigned a permanent bed at the next shift change.

Patient departure

Another event type is a patient departure. When this occurs, the model checks which patient is departing. In real-life, a patient departure would mean that the patient is moved to another health facility, that the patient has gone home, or that the patient has deceased. In the model, these actions are considered out of scope. So, in the simulation, the model simply finds the departing patient and discharges them from the NICU and updates the number of available beds and cumulative patient acuity at the NICU are updated.

Week change

The final event type in the model are week changes. The reason these changes are incorporated in the model is because the model assumes that the operational capacity is updated weekly. In real-life, operational capacity is dependent upon sickness and unforeseen instances. Since we do not have data on this, we have made this simplification in the model. For this, we have made several assumptions to determine the operational capacity of NICU locations in the model.

As discussed in Chapter 2, a distribution for the distribution of the percentage of operational capacity has been derived from the national data gathered by the WKZ. In the model, we assume that this distribution is the same for every NICU location. In real life, the number of operational beds is determined by availability of nurses. Data of the WKZ shows that on average, a nurse can operate two beds. This ratio is used to calculate the number of available nurses by means of the number of available beds. So, in the model, the operational capacity is calculated by dividing the the maximum number of beds by two and multiplying this with the generated percentage of operational capacity at that moment.

So when a week has passed in the model, the operational capacity for each NICU location is updated by drawing a random number and adjusting the capacity according to the distribution presented previously. It may happen that the cumulative patient acuity is then higher than the number of nurses present at a NICU location. However, the model assumes that in these instances, the available nurses are able to temporarily cope with a higher workload. This fortunately will not last long, as the under-staffing will be solved during the next nurse change.

E CHAINING CROSS-TRAINING POLICY REVERSED

The chaining cross-training policy can be followed clockwise or counterclockwise. The experiments with including all locations and varying the number of participating nurses are performed for both directions in the chaining policy to rule out any significant differences between the two. The results are shown in Figures E.1, E.2, E.3, and E.4. The chain direction that minimises the travel distance from the larger NICU locations (Amsterdam, Rotterdam, Utrecht) is shown in blue and the other direction is shown in green. The results show that there are no significant differences between the two routes when looking at the percentage of rejected patients and the percentage of transported patients. We have chosen to only present the route that minimises travel from large NICU locations as this has a slightly lower percentage of transported nurses.

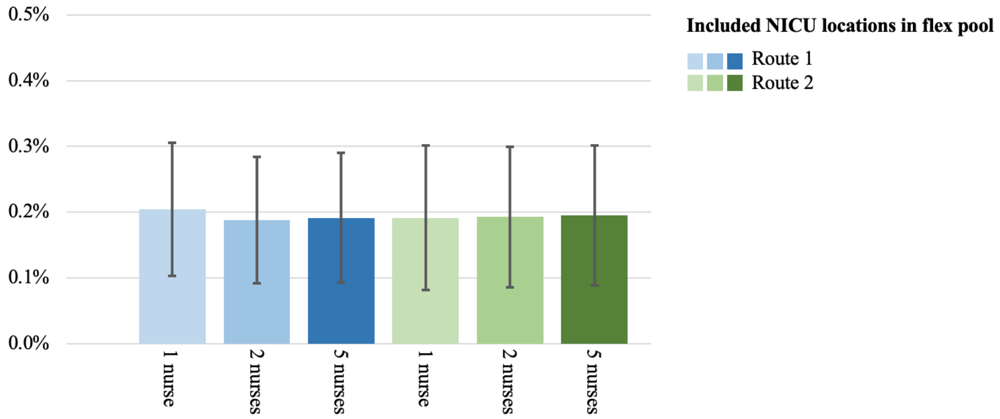


Figure E.1: Chaining cross-training policy - Number of rejected patients as a percentage of the total number of incoming patients (n = 82200, 0.1% equals approximately 4 rejected patients per year)

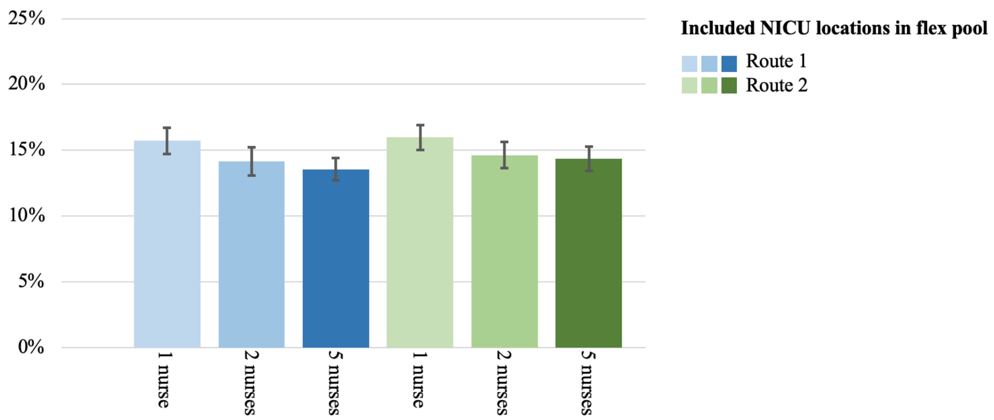


Figure E.2: Chaining cross-training policy - Number of transported patients as a percentage of the total number of incoming patients (n = 82200, 10% equals approximately 400 transported patients per year))

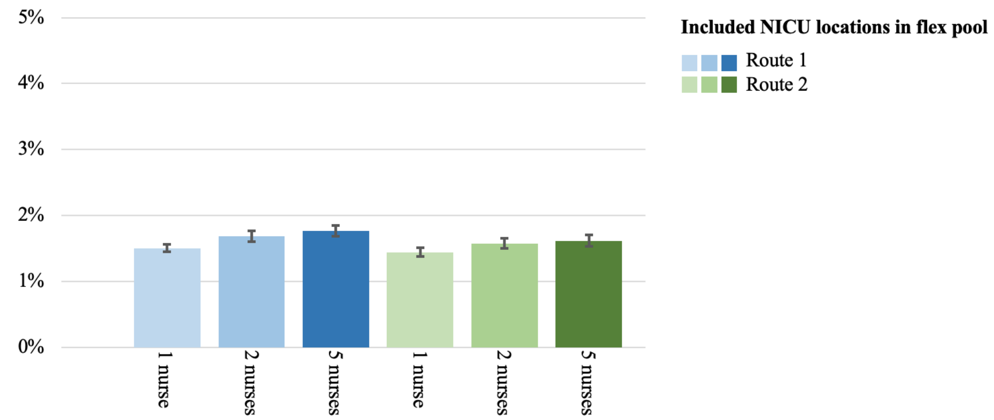


Figure E.3: Chaining cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all nurses (n = 1,714,216 shifts, 1% equals approximately 8500 nurse transfers per year))

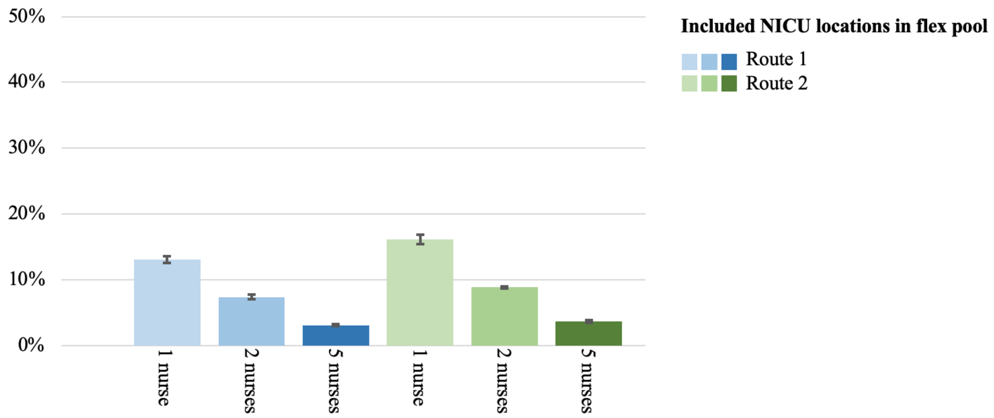


Figure E.4: Chaining cross-training policy - Number of shifts in which a flex nurse is transferred as a percentage of the total number of shifts of all nurses (1% equals approximately 980 nurse transfers per year)