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Effects of implementation of the trauma care norms in trauma patient logistics

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Preface

Dear reader,

Before you is my master's thesis, titled 'Effects of implementation of the trauma care norms in trauma patient logistics', completed as part of the Industrial Engineering & Management program. This research was carried out at Acute Zorg Euregio in collaboration with the National Network of Acute Care (LNAZ). It represents the conclusion of my academic journey as a student, marking the conclusion of my Bachelor's and Master's studies at the University of Twente, where I gained valuable insights and knowledge.

I express my sincere gratitude to everyone at Acute Zorg Euregio, who made my thesis-writing experience truly enjoyable. The environment was always welcoming and I felt like a part of the team rather than just a student conducting their thesis at the company. Special thanks to Nancy ter Bogt, my supervisor at the company, who consistently provided guidance, feedback and support. Her commitment, including the time she dedicated to helping me overcome challenges and co-presenting at various events, is truly appreciated.

I also express my appreciation to my academic supervisors at the University of Twente, Derya Demirtas and Sebastian Rachuba. Their extensive feedback on each iteration of my report proved invaluable in shaping the final version. Despite their busy schedules, they always made time for me. I am grateful to Derya for providing me with the opportunity to present my research at CHOIR, providing exposure to the field of operations research and healthcare management. Sebastian's active involvement as a second supervisor exceeded my expectations and his feedback greatly contributed to this research.

Acknowledgments also go to the national project group, whose input and opinions played a crucial role in the model's decision-making process. I am grateful for their collaboration and the insightful discussions that influenced my research. Additionally, I extend my thanks to all those who attended the presentations I delivered during this research, showing interest in my research.

Finally, I express my gratitude to my family, friends and my girlfriend for their invaluable support throughout the process of conducting this research. I take great pride in the outcome of this study and sincerely hope you find as much pleasure in reading my thesis as I did in undertaking this research!

Ruben de Boer

Hengelo, January 2024

Management summary

Problem definition

In the Netherlands, severely injured (multitrauma) patients receive specialized trauma care at major trauma centers (MTCs). These specialized hospitals are equipped with advanced resources and staffed by trauma care specialists to deliver comprehensive treatment. A network of healthcare providers, including hospital departments, emergency medical services and mobile medical teams (MMTs) collaborate in the trauma care chain to optimize patient care. The system faces considerable challenges in meeting the minimum volume and 90% norms. The minimum volume norm requires each MTC to treat a minimum of 240 multitrauma patients annually, while the 90% norm requires 90% of multitrauma patients in each region to be directly transported to an MTC. Adhering to these norms is crucial to ensure optimal care for trauma patients, enhancing their chances of recovery and survival. In 2022, the nationwide compliance score with the 90% norm was 70%, as none of the 11 regions met the requirement and 9 out of 13 MTCs fulfilled the minimum volume norm.

This research seeks to enhance comprehension regarding the impact of meeting the minimum volume and 90% norms on patient transportation time, emergency medical service busyness and hospital capacity. The core problem addressed in this research is:

What are the consequences of meeting trauma norms for acute care healthcare organizations in the Netherlands on patient transportation time, emergency medical service busyness and hospital capacity?

Approach

To offer insights, a predictive model is developed to mirror the prehospital trauma care system closely. The assessment of the prehospital trauma care system initially focused on identifying the components of this system and evaluating the adherence of MTCs and regions to the trauma norms. Following this, a literature review explored existing models and theories applicable to constructing various processes within the model.

The developed discrete-event simulation model includes various elements, e.g., three distinct vehicles (ambulances, MMT helicopters and ground vehicles) with unique characteristics, variations in incident severity and distinctions between MTCs and regional hospitals in the Netherlands. It calculates different prehospital time intervals by considering factors such as vehicle type, urgency of deployment, incident severity, transportation vehicle choice, selected hospital and potential deviations due to traffic and weather conditions. The model employs probabilities derived from available data from the Dutch Trauma Registry of 2022 to simulate decisions typically made in real scenarios, such as selecting appropriate vehicles, determining their origin and identifying the nearest suitable hospital for patients.

Various experiments were conducted with this model to observe their effects on the trauma norms, prehospital times and busyness of the emergency medical services. These experiments included achieving the 90% norm by increasing the probability of sending multitrauma patients to MTCs, increasing the overtriage percentage (directing more patients to MTCs, originally bound for regional hospitals, improving the chances of multitrauma patients ending up at the right place), implementing recent changes of 2023 in trauma care (such as excluding MTC status for the Vrije Universitair Medisch Centrum in Amsterdam and HagaZiekenhuis in The Hague) and introducing time thresholds of 30 and 20 minutes for using helicopters as transport vehicles instead of ambulances when the helicopter is deployed for the incident. Sensitivity analyses were also carried out, incorporating modifications to the number of trauma patients and ambulances in these experiments.

Results

Achieving the 90% norm in the model results in an increase to 10 MTCs meeting the minimum volume norm. When the overtriage percentage is increased, 11 MTCs fulfill the volume norm and while the 90% norm score improves, only 85% of multitrauma patients are directly transported to MTCs instead of the targeted 90%. Implementing 2023 changes results in 10 MTCs meeting the volume norm, with a total of 11 MTCs instead of the original 13.

Meeting the 90% norm and increasing the overtriage percentage extend transportation and total prehospital times for multitrauma patients on average by 3.5 and 2.5 minutes, respectively. Helicopter transport thresholds reduce times by about 1 and 1.5 minutes for 30-minute and 20-minute thresholds. Non-multitrauma patients' transportation and total prehospital times remain consistent across all experiments, except in the increased overtriage experiment, where they notably spike with an increase of 7 minutes on average.

In the increased overtriage experiment, ambulance busyness increases by around 13%. The Helicopter Emergency Medical Service (HEMS) teams' busyness slightly varies across experiments, increasing in those targeting the 90% norm and the increased overtriage percentage but decreasing in those introducing helicopter transport thresholds. Helicopter thresholds of 30 and 20 minutes reduce HEMS cancellations by 8% and 27%, with the number of helicopter transports increasing by 40% and 150% within the model, respectively.

Trauma patient number variations do not affect the 90% norm score. A 10% change in patient numbers impacts the number of MTCs meeting the volume norm. Across the experiments, adjusted patient numbers resulted in one or two additional or fewer MTCs reaching the volume norm, particularly affecting those MTCs close to the threshold of treating 240 multitrauma patients. Variations in the number of ambulances have minimal impact on trauma norm scores. Response and total prehospital times experience a 1-minute increase for a 30% decrease in ambulances and approximately a 2-minute increase for a 60% decrease. A consistent pattern in busyness is observed, with a 30% ambulance decrease causing nearly a 50% increase and a 60% decrease leading to a 140% increase in busyness in the model. Reductions in ambulance numbers reduce HEMS cancellations, ranging from a 4% to 9% decrease for a 30% reduction and a 13% to 16% for a 60% reduction in ambulances.

Conclusion

Meeting the 90% norm leads to an average increase of around 3.5 minutes in transportation and total prehospital times for multitrauma patients. Despite this increase, the busyness of emergency medical services would remain constant, as the prolonged prehospital times primarily impact the smaller subgroup of multitrauma patients. The rise in the number of patients within MTCs is minimal when the 90% norm is achieved. However, adopting a more random approach in selecting patients for transport to the MTCs, as seen in the experiment involving an overtriage percentage increase to 50%, results in a substantial influx of trauma patients in MTCs. This leads to longer prehospital times and, consequently, increased busyness of emergency medical services. It is important to note that increasing the overtriage percentage to 50% does not ensure the achievement of the 90% norm.

The implementation of changes in 2023 does not influence the 90% norm, but it does positively impact the number of MTCs meeting the minimum volume norm. The increased use of helicopters as transport vehicles may reduce the transport and prehospital times of multitrauma patients, but it does not affect either the minimum volume norm or the score on the 90% norm.

Key considerations regarding the displayed busyness in the model include that it exclusively focuses on trauma-related incidents. Therefore, the apparent low busyness may be deceptive since ambulances and HEMS are marked as busy only when actively deployed for trauma patients within the model. The busyness value is primarily employed for comparing different experiments. Furthermore, the seemingly counterintuitive decrease in HEMS busyness in experiments with increased helicopter usage for transport can be attributed to the model's perspective. In the model, HEMS is considered busy even when traveling to the hospital without a patient, awaiting the ambulance with the patient and the HEMS physician. The assumption in the model is that the HEMS physician always accompanies the ambulance when selected as the transport vehicle, provided the HEMS is also present at the scene.

Additionally, the model anticipates a reduction in the number of HEMS cancellations in experiments introducing time thresholds for using helicopters as transport vehicles. This is because the helicopter is more frequently selected as the means of transport, completing its journey more consistently within the model. Lastly, the model's validity is substantiated by closely aligning the number of multitrauma patients at each MTC and the 90% norm score in each region within a 5% margin of reality. The prehospital times determined by the model also conform to the data from the Dutch Trauma Registry.

Table of Contents

List of Tables 8

List of Figures 8

Glossary 9

1. Introduction 10

  1.1 Background information 10

  1.2 Problem description 11

    1.2.1 The minimum volume norm 13

    1.2.2 The 90% norm 13

  1.3 Core problem 14

  1.4 Problem approach 14

    1.4.1 Research problems and questions 15

    1.4.2 Scope 16

  1.5 Chapter summary 16

2. Context 17

  2.1 Prehospital care pathway 17

  2.2 Organization of EMSs 19

    2.2.1 Ambulance services 19

    2.2.2 Mobile Medical Teams 20

    2.2.3 Factors influencing EMS mode selection 21

  2.3 Organization of hospitals 21

  2.4 Current scores on trauma norms 22

  2.5 Stakeholders 24

  2.6 Chapter summary 24

3. Literature review 25

  3.1 Models prehospital care system 25

    3.1.1 EMSs and hospitals 25

    3.1.2 Incidents 26

    3.1.3 Dispatch policies 26

    3.1.4 Travel models 27

  3.2 Patient transportation modes 28

  3.3 Limitations 29

  3.4 Chapter summary 29

4. Model 31

  4.1 Model scope 31

  4.2 Model design 32

4.3 Assumptions and simplifications 32

4.4 Parameters and variables 35

4.4.1 Input model 35

4.4.2 Entities 35

4.5 Model explanation and functionality 39

4.6 Key Performance Indicators 41

4.7 Validation 42

4.8 Chapter summary 43

5. Experimental design 44

5.1 Experiments 44

5.2 Results experiments 45

5.3 Sensitivity analysis 46

5.3.1 Adjusting the number of patients 46

5.3.2 Adjusting the number of ambulances 48

5.4 Chapter summary 50

6. Conclusion 51

6.1 Conclusion 51

6.2 Discussion 52

6.3 Future research 54

References 55

Appendix A: Probability distributions 63

Appendix B: Flowcharts of the simulation model logic 65

Appendix C: Validation procedure 74

List of Tables

Table 1: Mobile Medical Teams (AmbuMedia, 2016; Instituut Fysieke Veiligheid, 2021) 21
Table 2: MTCs and their corresponding regions in 2022 (Kramer & Leenen, 2022) 22
Table 3: Scores on trauma norms 2022 (Zorginstituut Nederland, 2023b) 23
Table 4: Patient variables 36
Table 5: Ambulance variables 37
Table 6: Helicopter and ground vehicle variables 37
Table 7: HEMS physician variables 38
Table 8: KPIs 42
Table 9: Differences between model and reality - score on 90% norm 42
Table 10: Differences between model and reality - multitrauma patients at each MTC 43
Table 11: Aggregating multitrauma patients in NAZW 43
Table 12: Comparison prehospital time intervals A1 deployments and multitrauma patients in minutes 43
Table 13: Comparisons prehospital time intervals A2 deployments and trauma patients in minutes. 43
Table 14: Results of the model including decrease and increase of the number of patients by 10% .. 47
Table 15: Results reducing the number of ambulances in the model 49
Table 16: Difference between in- and excluding multitrauma patients with their own transport 74
Table 17: Difference between in- and excluding all trauma patients with their own transport 74
Table 18: Min, max and the average number of multitrauma patients within the MTCs across simulation runs 76
Table 19: Min, max and the average score on the 90% norm across simulation runs 76

List of Figures

Figure 1: Problem cluster 12
Figure 2: Prehospital care pathway (Harmsen, 2017) 17
Figure 3: Prehospital time intervals 18
Figure 4: Types of EMSs (Ambulancezorg Nederland, 2021c; Instituut Fysieke Veiligheid, 2021; Radboud UMC, n.d.) 19
Figure 5: Flow chart of the high-level process in the simulation model 39
Figure 6: Distribution response time A1 deployments (α = 6.74, β = 90.80) 63
Figure 7: Example distribution travel time: 10 minutes (μ = 600, σ = 30) 64
Figure 8: Distribution treatment time ISS>24 (α = 2.65, β = 564.12) 64
Figure 9: Distribution handover time A1 deployments (α = 16.85, β = 65.68) 64
Figure 10: Flowchart of the process of generating an incident 65
Figure 11: Flowchart of the process of dispatching EMS(s) 67
Figure 12: Flowchart of the process of carrying out the treatment 69
Figure 13: Flowchart of the process of choosing the transportation mode 70
Figure 14: Flowchart of the process of selecting an appropriate hospital 71
Figure 15: Flowchart of the process of transporting and handing over the patient 72
Figure 16: Number of multitrauma patients in the MTCs across simulation runs 75
Figure 17: Score on the 90% norm across simulation runs 76

Glossary

Term	Definition
90% norm	Trauma norm that states that at least 90% of multitrauma patients in the trauma regions should be transported to an MTC directly
A1 deployment	Ambulance deployment with high urgency in which the ambulance drives with sirens and should reach the scene within 15 minutes after the emergency call
A2 deployment	Ambulance deployment with lower urgency in which the ambulance should reach the scene within 30 minutes after the emergency call
AZE	Acute Zorg Euregio
Busy probability	Within this research, a probability that determines if a vehicle is occupied with non-trauma-related cases
Busyness	Within this research, the time a vehicle is occupied with trauma-related cases. From the moment the vehicle is deployed until it becomes available for the next incident
DES	Discrete Event Simulation
EMS(s)	Emergency Medical Service(s), provide urgent prehospital treatment for serious illness and injury
HEMS team(s)	Helicopter Emergency Medical Service team(s), include a trauma helicopter and, in many cases, a ground vehicle
ISS	Injury Severity Score, a complex scoring system used in traumatology to assign points to specific injuries, ranges from 0 to 75
Level II & III hospitals	Regional hospitals / Non-MTC hospitals
LNAZ	National Network of Acute Care (Dutch: Landelijk Netwerk Acute Zorg)
LTR	Dutch Trauma Registry (Dutch: Landelijke Traumaregistratie)
Minimum volume norm	Trauma norm that states that each MTC should accommodate at least 240 multitrauma patients per year
MMT(s)	Mobile Medical Team(s), deployed in case of severely injured patients in addition to the ambulance services
MTC(s)	Major Trauma Center(s), hospitals equipped to provide the most extensive trauma care
Multitrauma patients	Patients with an ISS > 15
Overtriage	Non-multitrauma patients transported to MTCs
Primary dispatch	Dispatch of an MMT upon receiving an emergency call
RAV(s)	Regional Ambulance Service(s) (Dutch: Regionale Ambulancevoorziening)
Response time	Time from incident reporting to EMS arrival at the incident
ROAZ regions	Acute care networks (Dutch: Regionaal Overleg Acute Zorgketen regio's)
Secondary dispatch	Dispatch of an MMT upon request of ambulance staff at the scene
Specially equipped priority vehicle	Ground vehicle of the HEMS team
Total prehospital time	Time from incident reporting to arrival at the hospital
Trauma care	Care for patients who got injured during an incident
Triage	Assessment of injuries and urgency of care
Under-triage	Multitrauma patients transported to non-MTC hospitals

1. Introduction

This chapter introduces the topic of the study, beginning with background information and challenges related to the trauma care chain. The core problem is identified and research questions and a plan of approach are formulated.

1.1 Background information

Acute Zorg Euregio (AZE) is one of eleven regional network organizations in the Netherlands designated to optimize the collaboration of all regional providers in the emergency care chain. Established in 1999, these organizations are part of the major trauma centers (MTCs). In the Netherlands, trauma care for severely injured patients is concentrated in MTCs. These hospitals are designated hospitals equipped with advanced resources, such as neurosurgical facilities and other damage control resources and are staffed by experts in trauma care to provide the most extensive trauma care (van Ditshuizen et al., 2023). In 2022, 13 hospitals in the Netherlands are designated as MTCs (Kramer & Leenen, 2022).

Trauma care is a specialized form of medical care that focuses on treating patients who have experienced severe physical injuries, often caused by accidents, falls, serious burns, assaults or other traumatic events (Bradburn, 2022). Trauma care involves a coordinated and multidisciplinary approach, with medical staff from different specialties working together to provide timely and appropriate care to patients (Bach et al., 2017). Within trauma care, a distinction is made between trauma and multitrauma patients based on the Injury Severity Score (ISS).

The ISS is a complex scoring system used in traumatology to assign points to specific injuries. The score ranges from 0 to 75, with higher scores indicating more severe injuries. When the ISS exceeds 15, the patient is classified as a multitrauma patient, rather than a trauma patient (Roden-Foreman et al., 2019). Multitrauma patients, who represent approximately 7% of the entire group of trauma patients in 2021, often have more severe and complex injuries and thus may require different or more specialized forms of care (Kramer & Leenen, 2022). This research especially focuses on the group of multitrauma patients because they affect the relevant trauma norms to this report.

Multiple healthcare providers, such as hospital departments, emergency departments, regional ambulance services and mobile medical teams collaborate within the trauma care chain to optimize the care for trauma patients (AZEUR, 2018). This system is faced with several challenges, such as the global issue of personnel shortages and the resulting pressure on the healthcare system, which can have significant consequences (Winter et al., 2020). However, this research will focus on specific challenges related to the Dutch trauma care system. Two major challenges facing this system are satisfying the minimum volume and 90% norms. The minimum volume norm requires each MTC to treat at least 240 multitrauma patients annually. This is crucial for ensuring that MTCs have sufficient experience and expertise to provide high-quality trauma care. The 90% norm stipulates that 90% of severely injured patients in each region should be directly transported to an MTC. Meeting these norms is essential to ensure that trauma patients receive the best possible care and improve their chances of recovery and survival.

At the beginning of 2022, Meijer (2022) initiated research that involved modeling the Dutch trauma care system using publicly available data. This modeling is also relevant for this research, where the focus is on meeting the minimum volume and 90% norm. Contrary to the study of Meijer, there is now permission from the Scientific Advisory Board of the Dutch Trauma Registry to use data from the Dutch Trauma Registry (LTR), which contains comprehensive data on trauma care in the Netherlands.

1.2 Problem description

Acute Zorg Euregio in collaboration with the National Network of Acute Care (LNAZ, Dutch: Landelijk Netwerk Acute Zorg) aims to improve their understanding of the effects on patient transportation time, emergency medical service capacity and hospital capacity when meeting the minimum volume and 90% norms. To achieve this aim, an extensive problem cluster has been created to identify related problems and potential causes or consequences of this topic. The problem cluster helps to identify the core problem, research problems and research questions. This approach can facilitate a solution for this research more effectively and efficiently. Figure 1 shows the problem cluster, with the result at the top and the causes at the bottom. The orange-colored boxes indicate the trauma norms that are not met and the gray-colored boxes visualize the effects we are interested in for this research.

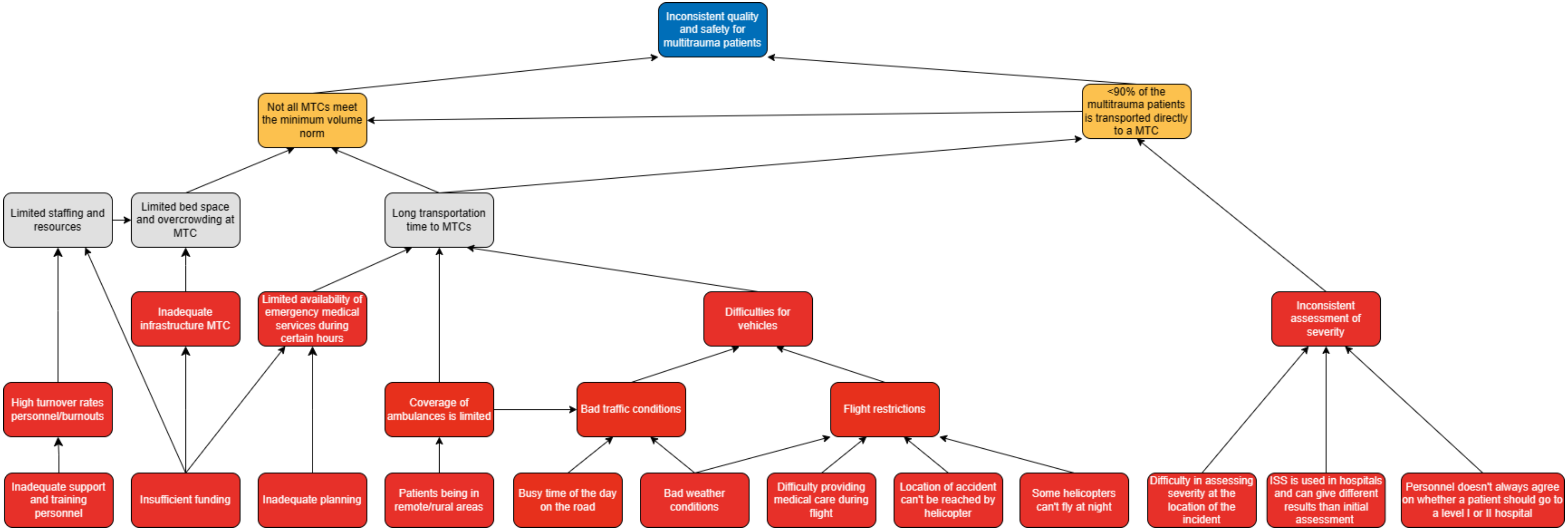


Figure 1: Problem cluster

1.2.1 The minimum volume norm

As seen in the problem cluster, not all MTCs meet the minimum volume norm of treating at least 240 multitrauma patients annually (Kramer & Leenen, 2022). Several factors contribute to this, such as long transportation time to MTCs and not meeting the 90% norm. Limited staffing and resources within MTCs and inadequate infrastructure may cause limited bed space and overcrowding, though, rarely, an MTC does not have a bed available for multitrauma patients as they must keep beds free for multitrauma patients (NVT, 2020). Insufficient funding is a root cause of staffing and resource problems, which also results in high turnover rates and burnouts caused by inadequate support and training of personnel (IZZ, 2019).

Concerning the long transportation time to MTCs, one contributing factor could be the absence of available emergency medical services in a certain area at specific times of the day, either due to planning or limited funding. Conditions affecting the Emergency Medical Service (EMS) vehicles can also play a role in the long transportation time. The EMS consists of ambulance services and the Mobile Medical Team (MMT). Ambulance services are the first to be dispatched and are often used to transport the patient to the hospital (Meijer, 2022). The MMT is deployed by the control room operator in the event of severe or large-scale accidents. It is also deployed when certain serious medical conditions are immediately life-threatening and where acute specialist assistance is required on-site. The team has a helicopter and a specially equipped priority vehicle at its disposal. The use of the helicopter is preferred by the MMT due to its high speed and greater coverage (Radboud UMC, n.d.).

Ambulances can take longer to reach the MTCs due to road congestion or limited coverage of ambulances (Spoelder et al., 2022). Patients located in remote or rural areas cause ambulances to be on the road longer, so they are occupied for longer and can therefore not be used for other patients in the meantime (Morgan & Calleja, 2020). The sometimes big distances to the nearest MTCs are unsolvable because the concentration of trauma care in the MTCs naturally increased these distances (Meijer, 2022). Bad weather can further complicate transportation, especially for helicopters, which may not be able to fly at all (Oude Alink et al., 2022). There are also additional challenges for helicopters, such as that the German helicopters that provide support in the regions near the Dutch border cannot be used at night, difficulties in providing medical assistance during the flight to an MTC and some locations cannot be reached such as densely populated areas (ADAC Luftrettung, n.d.-a, n.d.-b; Kramer & Leenen, 2022; Timm et al., 2019). In some cases, rendezvous points are required at which the helicopter can meet an ambulance carrying the patient (Furuta & Tanaka, 2014).

1.2.2 The 90% norm

The 90% norm remains unmet as the percentage of multitrauma patients directly transported to an MTC falls below the 90% threshold. This is also one of the reasons why some MTCs cannot meet the minimum volume norm (Kramer & Leenen, 2022). By increasing the number of multitrauma patients directly transported to an MTC, more multitrauma patients can receive prompt and suitable treatment on an annual basis. However, one significant reason why less than 90% of multitrauma patients are taken directly to an MTC is the long transportation times. Research has shown that longer ground transport times and the presence of closer non-MTCs lead to a lower percentage of multitrauma patients directly transported to an MTC. In 2015 and 2016, EMS decided not to bypass non-MTC hospitals for nearly 30% of multitrauma patients if these hospitals were the closest instead of transporting them to an MTC (Sturms et al., 2021).

An inconsistent assessment of the severity of the injury is another important reason that the second norm is not met. Initially, medical staff assesses the injury severity based on prehospital triage criteria of the National Ambulance Care Protocol (Ambulancezorg Nederland, n.d.-a). However, a second assessment is conducted in the hospital using the ISS, which is based on the Abbreviated Injury Scale (AIS) data. The AIS data provides an anatomically-based, mortality-weighted code set used to classify injury severity (Van Ditshuizen et al., 2021). The 90% norm is based on the ISS and this differs from the initial assessment where the prehospital triage criteria are used. At the scene of the incident, ISS can't be used to identify multitrauma patients, which can result in patients not being taken to an MTC initially (Newgard et al., 2008).

The last cause listed in the problem cluster why the assessment of the severity of the injury is inconsistent is that the medical staff sometimes don't agree on whether a patient should go to an MTC or a non-MTC hospital. An example of this can be that according to the criteria, a patient must be transported to an MTC but the medical staff thinks that it is better for the health of the patient to transport the patient to a hospital that is not an MTC that is closer.

1.3 Core problem

The core problem of this research is the following:

What are the consequences of meeting trauma norms for acute care organizations in the Netherlands on patient transportation time, emergency medical service busyness and hospital capacity?

The core problem is addressed by investigating relevant literature related to trauma care, developing a mathematical model to simulate different scenarios and conducting experiments to test different solutions. The goal is to provide an extensive analysis of the consequences of meeting trauma norms. To structure the research, research problems and questions have been formulated.

1.4 Problem approach

This research uses a quantitative research design to approach the problem. Given the nature of the research, correlational and descriptive research designs are considered the most suitable methods (Bloomfield & Fisher, 2019). This research aims to determine relationships between different variables and to describe and summarize the data and outcomes, which is achieved through a correlational and descriptive approach. The first step of this approach is defining the problem and the research questions. After the problem and research questions are determined, a literature review is conducted to find more information about existing material and gaps that remain on the subject. The third step involves deciding which parameters/outcomes will be measured and used for the model.

The data collection techniques used for this research are secondary data analysis and focus groups (Szabo & Strang, 1997). Secondary data analysis involves analyzing data from the Dutch Trauma Registry and the ambulances, last year's research on the concentration of MTC based on public data by Meijer (2022) and literature studies. Meetings with a national project group consisting of various experts from the different trauma regions in the Netherlands can be seen as focus groups. With a model, the data is processed and analyzed to derive results that are justified by the research questions. From these results, conclusions are drawn and recommendations are made. The final step is to complete the report, summarize all the findings and discuss their implications for future practice and research.

1.4.1 Research problems and questions

This section outlines the specific research problems and questions that are addressed in this research. Each research problem has several research questions that together provide an answer to the research problem. The following research problems and questions guide the report and investigate different topics related to the Dutch trauma care chain.

The first research problem addressed is the current situation of the trauma care chain and the trauma norms across the Netherlands. It is necessary to understand the current situation before looking at possible future effects. Knowing more about the pathway and how the MTCs and EMSs are organized is a good start to this research. How well the MTCs currently score on the trauma norms is also important for understanding the current situation and the problem.

1. How is the current trauma care chain organized and how are the trauma norms currently being implemented in multitrauma healthcare organizations across the Netherlands?
    - 1.1 What is the pathway for providing prehospital care to multitrauma patients?
    - 1.2 How are the major trauma centers (MTCs) organized?
    - 1.3 How are the emergency medical services (EMSs) organized?
    - 1.4 How do the major trauma centers currently score on the trauma norms?

The second research problem is about what is already known in the literature about the consequences of meeting trauma norms in healthcare organizations but also about what information/topics are still missing. This question also looks at which models have already been made for related topics and what useful theory is available for creating parts of the model. This literature review aims to provide a comprehensive overview of existing literature on this topic and identify the key findings and gaps.

2. What is the current state of knowledge on the impact of meeting trauma norms on patient transportation time, emergency medical service capacity and hospital capacity and what are the key gaps and limitations in existing literature?
    - 2.1 What are the key concepts and definitions related to trauma norms?
    - 2.2 Which models are suitable for evaluating the impact of meeting trauma norms?
    - 2.3 Which emergency medical service mode is best to use in which situation?
    - 2.4 What gaps and limitations exist in existing literature related to meeting the trauma norms?

For the third research problem, we look at how the model is put together and which aspects are important for creating and using this model. The model aims to provide a framework for understanding the impact of meeting trauma norms in healthcare organizations in the Netherlands and to test different scenarios.

3. How can available relevant information and a model be used to determine the effects of meeting trauma norms on patient transportation time, emergency medical service capacity and hospital capacity?
    - 3.1 Which parameters and variables need to be considered and how can they be quantified and measured?
    - 3.2 What are the key assumptions and simplifications?

The fourth research problem looks at the different scenarios included in the experiments and how these scenarios can be compared with each other using KPIs. This experimental design will form an essential part of the analysis, conclusions and recommendations.

4. What scenarios will be considered during the experiments and how can they be compared to each other?
    4.1 Which Key Performance Indicators (KPIs) are important?
    4.2 What are several implementation strategies that can positively impact meeting the trauma norms?

The last research problem focuses on the results of the model and experiments. The differences between the scenarios and the effects on the transportation time of patients, the capacity of emergency medical services and the capacity of the hospitals are discussed in more detail here.

5. What are the results of the model and the experiments?
    5.1 What are the results of the different scenarios?
    5.2 What are the effects on the transportation time of patients?
    5.3 What are the effects on the capacity of emergency medical services?
    5.4 What are the effects on the capacity of the hospitals?

1.4.2 Scope

This research is centered around the trauma system in the Netherlands, with a focus on the prehospital phase. This prehospital phase includes the moment of the emergency call, the emergency medical dispatch, the arrival at the incident's location and the patient's transport up to the arrival of the patient at the Emergency Department. We focus on the logistical aspects of hospitals and regional trauma centers, as well as the deployment of ambulances and MMTs. Performance indicators related to the quality of care and costs fall outside the scope of this research.

1.5 Chapter summary

This research focuses on the prehospital phase of the Dutch trauma system from the moment of the emergency call up to the arrival of the patient at the Emergency Department. This chapter highlights the challenges faced by the Dutch trauma care system, specifically addressing the implications of not meeting the minimum volume and 90% norms. The minimum volume norm requires each MTC to treat at least 240 patients annually and the 90% norm stipulates that 90% of severely injured patients in each region should be directly transported to an MTC. Meeting these norms is essential for ensuring that trauma patients receive the best possible care and improve their chances of recovery and survival. Acute Zorg Euregio in collaboration with the National Network of Acute Care aims to improve their understanding of the effects of compliance with the trauma norms on patient transportation time, emergency medical service capacity and hospital capacity. A model is created for this research to map the possible effects and provide results, conclusions and recommendations justified by the research questions.

2. Context

This chapter provides an overview of the Dutch trauma system, including its prehospital care pathway and the organization of the EMSs and hospitals. It also shows how different regions and MTCs currently score on the trauma norms and identifies the stakeholders for this research.

2.1 Prehospital care pathway

After an incident occurs, several processes are set in motion before the patient reaches the hospital. Figure 2 illustrates the prehospital care pathway of the Dutch trauma system.

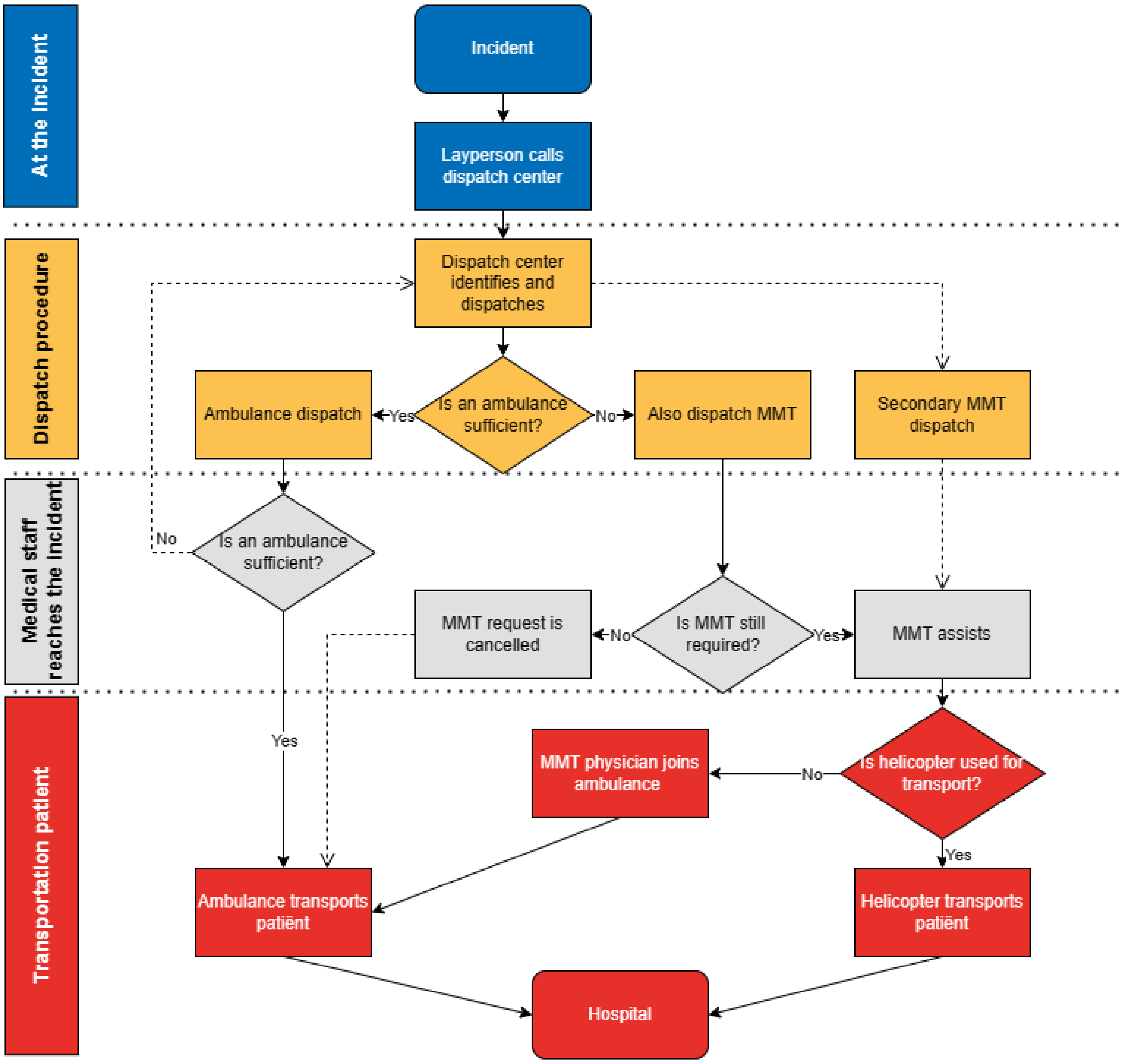


Figure 2: Prehospital care pathway (Harmsen, 2017)

When an incident occurs, a layperson or the patient calls the emergency number 112. The call is forwarded to the appropriate regional ambulance dispatching center. Based on the call, an emergency operator in the dispatch center identifies the severity of the incident and whether it is necessary to deploy the MMT in addition to an ambulance. The emergency operator employs dispatch criteria that take into consideration factors such as the patient's consciousness, condition, age and the nature of the report when making the decision (LNAZ, 2013). When it is decided to also dispatch the MMT, it is referred to as a primary dispatch. Ambulances often arrive first at the location of the incident, where they evaluate the situation and report back to the dispatch center and the MMTs with a situational report (Harmsen, 2017). Based on this information, the ambulance crew can, for example, choose to call in reinforcements from an MMT if that choice has not been made before. If this happens, it is referred to as a secondary dispatch. It is also possible for the ambulance crew to cancel the MMT dispatch in case they appear not to be necessary (Giannakopoulos et al., 2010). There may be various reasons for this, such as the absence of abnormal vital functions in the patient, the patient not being severely injured, the MMT being unable to reach the incident in time or the patient having already passed away (LNAZ, 2013). In the event of a cancellation or when no MMT has been dispatched at all, the ambulance crew themselves provide the necessary care at the location and then transport the patient to a hospital. The secondary dispatch process and the MMT cancellation can be seen as dotted lines in Figure 2.

If the MMT is deployed and not canceled, it will provide medical assistance at the location of the incident regardless of whether it is a primary or secondary dispatch. The MMT arrives with a helicopter or a specially equipped priority vehicle, but the latter can't transport patients (Radboud UMC, n.d.). Therefore, the choice of transportation is between an ambulance or the MMT helicopter. Generally, the ambulance is preferred for transportation because there is more space for the crew to provide care to the patient during transport and it is usually the fastest option to reach a hospital in the Netherlands (Bulger et al., 2012; Oude Alink et al., 2021). The helicopter is used in cases where the patient is located in a remote area, the site is not easily accessible or a suitable hospital is too far away by ground. If the ambulance is chosen, the MMT physician accompanies the patient in the ambulance to the hospital (Den Hartog et al., 2015).

The total prehospital time and the busyness of the EMS, as depicted in Figure 3, consists of various phases. When an incident occurs, it is reported and a decision is made regarding which EMS(s) will be dispatched. The EMS requires time for deployment and then proceeds to the incident location. The duration from incident reporting to EMS arrival at the scene is defined as the response time. Subsequently, the on-scene phase commences, during which the patient is treated and the time required to load the patient into the vehicle is recorded. Following this phase, transportation to the hospital begins and the total prehospital time concludes upon arrival at the hospital.

It's important to note that the handover of the patient from the transport vehicle to the hospital's emergency department is no longer considered a part of the total prehospital time. However, this handover process remains relevant when assessing the busyness of the EMS. The EMS is considered "busy" from the moment they are deployed until they become available for the next incident.

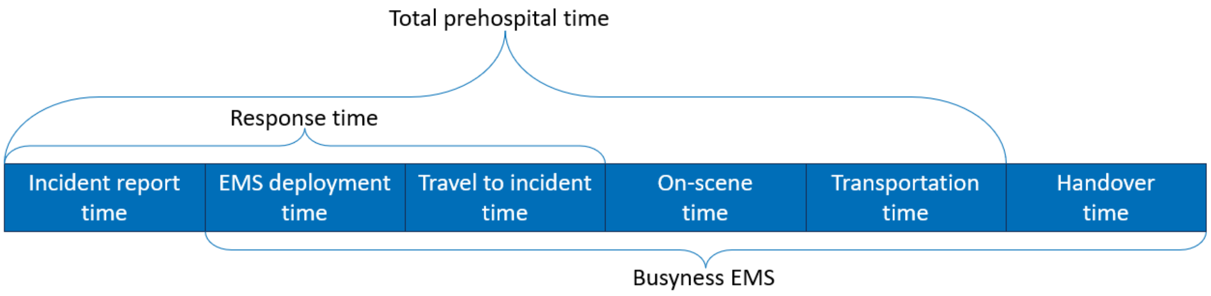


Figure 3: Prehospital time intervals

2.2 Organization of EMSs

The EMSs play a critical role in the trauma system. This section provides further details on the EMS vehicles and the personnel present in these vehicles, as well as the stations and the various EMS types as illustrated in Figure 4.

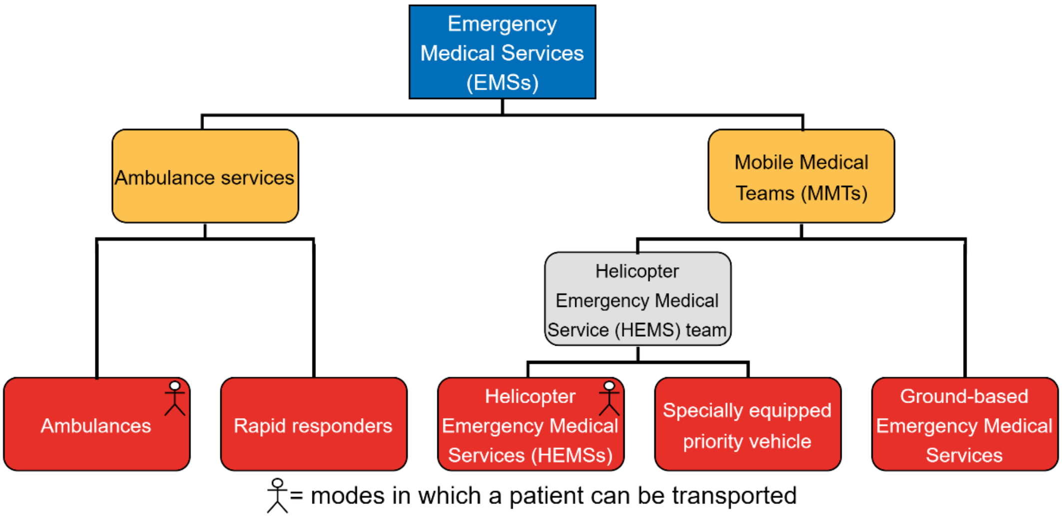


Figure 4: Types of EMSs (Ambulancezorg Nederland, 2021c; Instituut Fysieke Veiligheid, 2021; Radboud UMC, n.d.)

2.2.1 Ambulance services

In the Netherlands, ambulance services are typically the first responders to an emergency and are the most common mode of transportation for patients to a hospital. The ambulance crew consists of a specialized nurse with several years of experience in the emergency room, intensive care unit or anesthesia department, and an ambulance driver trained to assist the nurse during life support procedures (Oude Alink et al., 2021). An HEMS physician may also join the ambulance crew on the way to the hospital if an MMT has been deployed.

Besides the regular ambulances, there are also rapid responders. The rapid responder is an ambulance vehicle staffed by a nurse who acts independently on the incident's location (Ambulancezorg Nederland, 2021c). These vehicles are similar to complete ambulances in almost every way, but there are two key differences. Firstly, patients can't be transported in this vehicle, so another vehicle is required for transportation. Secondly, a nurse drives the vehicle alone, with no other person present in the vehicle. Rapid responders help manage peak demand and ease the workload of regular ambulances. The aim is to provide high-quality ambulance care more effectively and at a lower cost (RAV ZHZ, 2015).

Ambulance care in the Netherlands is organized regionally through Regional Ambulance Services (RAVs in Dutch), with the country being divided into 25 RAV regions (Ambulancezorg Nederland, 2021a). As of the end of 2021, there were 224 ambulance stations distributed throughout these regions in the Netherlands, providing a total of 900 ambulances. The location of the ambulance stations is based on that, under normal circumstances, 95% of the population in the Netherlands must be reached within 15 minutes from the moment the incident was reported (Ambulancezorg Nederland, 2022). This ensures that emergency medical care can be provided efficiently and quickly when needed.

The ambulance and rapid responder share similar activities and equipment. Although rapid responders have the advantage of faster response time, they cannot transport patients to hospitals. Rapid responders are useful when a fast first response to an emergency request is required in the outskirts of a region that ambulances cannot reach within the time threshold (Van Barneveld, van der Mei, et al., 2017). They are also suitable for on-site treatment of patients with expected minor injuries or insignificant conditions that do not require transportation (Breeman et al., 2018). However, this research focuses on trauma patients who require hospital transport, making it more relevant to examine the ambulances instead of the rapid responders. In actual situations, rapid responders are often deployed to cope with peak times of ambulance care, covering the preparedness of the region and providing relief to ambulances instead of replacing them (Veiligheidsregio Rotterdam-Rijnmond, 2016).

2.2.2 Mobile Medical Teams

An MMT is deployed in case of severely injured patients in addition to the ambulance service. Its main purpose is to bring specialized medical care to the scene as soon as possible (Aydin et al., 2010). The team consists of a physician, a nurse (also known as a Helicopter Crew Member or HCM), a pilot and some teams also have a driver (also called a Helicopter Landing Officer or HLO) (LNAZ, n.d.-b). The MMTs, sometimes in collaboration with MMTs stationed around the border area in Germany and Belgium, can reach up to 80% of the Dutch population within 15 minutes (LNAZ, 2021; NVT, 2017).

In the Netherlands, four MMTs exist that can use both a helicopter and a specially equipped priority vehicle. The helicopter flights are called Helicopter Emergency Medical Service (HEMS) flights. These flights are subject to specific laws and regulations which is why the MMT helicopter is allowed to land anywhere in the country. If the helicopter is unable to fly, for example, due to weather conditions or technical maintenance, the specially equipped priority vehicle will be deployed to reach the incident as quickly as possible (LNAZ, n.d.-b). Typically, the helicopter is the preferred option due to its ability to travel in a straight line, reach high speeds, cover long distances and access and transport patients who are in areas that are difficult to reach for ground vehicles such as rural areas (Andruszkow et al., 2013; Berkeveld et al., 2021). However, in urban areas where space is limited and situations where the incident is nearby, the priority vehicle is utilized as it can access areas that a helicopter cannot or can reach the destination quicker (Den Hartog et al., 2015). However, it cannot transport patients, so an ambulance is required to transport the patient to the hospital. For the primary dispatch, the decision of dispatch is done based on information provided by a layperson and the application of dispatch criteria. This information can be incomplete or incorrect so a low activation threshold for dispatch is used by the dispatch centers to minimize under-triage (Harmsen et al., 2015). Under-triage can be defined as the proportion of severely injured patients not managed by a dedicated trauma team or the admission of severely injured patients to a non-trauma center (Nordgarden et al., 2018; Tillmann et al., 2020). In the context of this study, the latter definition is adopted.

In addition to the four MMTs, there are also two ground-based MMTs called Ground-based Emergency Medical Services, located in Enschede and Utrecht. These teams require a short preparation time before use, don’t have a helicopter at their disposal and are only deployed in cases of large accidents involving ten or more patients (Instituut Fysieke Veiligheid, 2021). It is important to note that this research does not focus on large-scale accidents, which require the deployment of Ground-based Emergency Medical Services. Therefore the Ground-based Emergency Medical Services will not be considered in this research. Table 1 provides an overview of the various MMTs in the Netherlands and the corresponding locations of their stations. This table also includes two German HEMS stations close to the Dutch border, which are relevant to this research.

Table 1: Mobile Medical Teams (AmbuMedia, 2016; Instituut Fysieke Veiligheid, 2021)

Name	Location	Type
Lifeliner 1 – Amsterdam	Amsterdam Heliport	HEMS team
Lifeliner 2 – Rotterdam	Rotterdam The Hague Airport	HEMS team
Lifeliner 3 – Nijmegen	Volkel Air Base	HEMS team
Lifeliner 4 – Groningen	Groningen Airport Eelde	HEMS team
05-985	Enschede	Ground-based team
09-901	Utrecht	Ground-based team
Christoph Europa 1 – Würselen	Aachen Merzbrück Airfield	HEMS team
Christoph Europa 2 – Rheine	ADAC Air rescue station Rheine	HEMS team

2.2.3 Factors influencing EMS mode selection

Determining which type of EMS mode to use for a certain situation depends on several factors. Some of these factors are explained below (Elkbuli et al., 2021; Hu et al., 2020; Kramer & Leenen, 2022):

- *Location of the patient:* Some locations are difficult to reach for the specific vehicles, so another mode must be used.
- *Patient distance to MTC:* If the distance between the patient and the MTC increases, there is a bigger chance that a helicopter is used.
- *Type and severity of the injury:* The type and the severity of the patient's medical condition may determine which EMS mode is used. If a patient is in a critical condition and there is therefore an enormous rush to provide care to the patient, helicopters are deployed to assist the patient as quickly as possible.
- *Availability of resources:* The ambulances and helicopters together with the personnel must be available at deployment.
- *Time of day:* At night, for example, German helicopters can't be used.
- *Traffic conditions:* Traffic on the road can prevent ambulances from reaching the patient quickly.
- *Weather conditions:* Bad weather conditions such as fog and strong gusts of wind can prevent helicopters from being deployed.

The incidents are retrieved by the dispatch center, which uses various factors to determine the appropriate EMS mode and response location (Ambulancezorg Nederland, n.d.-b). The urgency of the incident is also taken into account, with two emergency categories available for urgent ambulance care: A1-deployment, with a target of on-site assistance within 15 minutes in 95% of cases and A2-deployment, with a maximum target of 30 minutes (Van der Erf et al., 2021). A1-deployments indicate a more urgent need for care, but the 15-minute target is not medically or scientifically substantiated. As a result, a plan has been developed to use a new urgency classification within the ambulance sector starting in 2023, with a greater focus on the quality of care rather than the 15-minute standard (Ambulancezorg Nederland, 2021b). With the new urgency classification, incidents previously categorized as A1-deployments are split into two categories: A1-deployments and A0-deployments, which represent the most severe cases.

2.3 Organization of hospitals

Hospitals in the Netherlands are organized at different levels based on the type of care they provide, with particular relevance to trauma care. The level criteria do not indicate the quality of care but rather provide insight into the presence of necessary facilities in a hospital for emergency medical assistance (LNAZ, n.d.-a). The hospitals are divided into three levels:

- Level I: All severely injured patients can be seen 24/7 and they provide the most comprehensive care. One of the conditions is that the intensive care unit has at least 12 beds, of which 1 is always available for an acute trauma patient (NVT, 2020).
- Level II: Critically endangered patients are accommodated here, but not all facilities are available.
- Level III: Isolated injuries can be treated here, for example, a hip or ankle fracture.

Within this report, MTCs refer to level I hospitals, while level II and level III hospitals are regarded as regional hospitals (Kramer & Leenen, 2022). To properly coordinate trauma care, the Minister of Health, Welfare and Sport designated hospitals as MTCs in 1999 (Borst-Eilers, 1999). Additionally, in 2008, the AMC received recognition as an additional MTC, contributing to the formation of a total of 11 regional acute care networks (Kramer & Leenen, 2022). However, as of 2023, two of these networks, Network Acute Care Northwest and SpoedZorgNet, have merged under a new name “Network Acute Care North-Holland/Flevoland”, resulting in a total of 10 regional acute care networks (NAZNH-FL, 2023). Each region had one MTC, except for the Network Acute Care West (NAZW), which had three MTCs in 2022. In 2023, each region has one trauma center, with the AMC serving as the trauma center for the newly formed Network Acute Care North-Holland/Flevoland. Network Acute Care West, however, has two trauma centers, namely the HMC and LUMC. Table 2 shows the list of Dutch MTCs and their regional networks. In the course of the report, we use the abbreviated names of the MTCs and the regions listed in brackets in the table.

Table 2: MTCs and their corresponding regions in 2022 (Kramer & Leenen, 2022)

MTC (*short name*)	Region (short name)	City
Medisch Spectrum Twente (*MST*)	Acute Care Euregio (*AZEUR*)	Enschede
Universitair Medisch Centrum Groningen (*UMCG*)	Acute Care Network North Netherlands (*AZNN*)	Groningen
Radboud Universitair Medisch Centrum (*Radboud UMC*)	Acute Care Region East (*AZO*)	Nijmegen
Elisabeth Tweesteden Ziekenhuis (*ETZ*)	Network Acute Care Brabant (*NAZB*)	Tilburg
Maastricht Universitair Medisch Centrum+ (*Maastricht UMC+*)	Network Acute Care Limburg (*NAZL*)	Maastricht
Vrije Universiteit Medisch Centrum (*VUmc*)	Network Acute Care Northwest (NAZNW)*	Amsterdam
Academisch Medisch Centrum (*AMC*)	SpoedZorgNet (SZN)*	Amsterdam
Isala Zwolle (*Isala*)	Network Acute Care Region Zwolle (*NAZZ*)	Zwolle
Leids Universitair Medisch Centrum (*LUMC*)	Network Acute Care West (NAZW)	Leiden
HagaZiekenhuis (*HagaZiekenhuis*)		The Hague
Haaglanden Medisch Centrum (*HMC*)		The Hague
Erasmus Medisch Centrum (*Erasmus MC*)	Trauma Center Southwest Netherlands (*TCZWN*)	Rotterdam
Universitair Medisch Centrum Utrecht (*UMC Utrecht*)	Network Acute Care Central Netherlands (*NAZMN*)	Utrecht

* Network Acute Care Northwest (NAZNW) and SpoedZorgNet (SZN) merged under one new name, Network Acute Care North-Holland/Flevoland (NAZNH-FL) in 2023

2.4 Current scores on trauma norms

This research aims to provide an extensive analysis of the consequences of meeting trauma norms. It is therefore also good to know how the MTCs and the regions are currently scoring on the norms, as well as the importance of these norms. In 2015, the National Health Care Institute (ZIN, Dutch: Zorginstituut Nederland) established the quality indicator that requires 90% of multitrauma patients to be directly transported to an MTC within the regions (Zorginstituut Nederland, 2015). In 2018, the minimum volume norm was introduced, which replaced the previous norm of treating at least 100 multitrauma patients annually. This change was made as research showed that treating larger numbers of complex patients leads to better outcomes (Bell et al., 2015; McCrum et al., 2014). These norms aim to concentrate the care for multitrauma patients in MTCs to enhance the quality of care and improve the patient's chances of survival (Moes et al., 2019).

Table 3 provides an overview of how many multitrauma patients were treated at the MTCs in 2022 and the fraction of multitrauma patients who were directly transported to an MTC within the regions.

Table 3: Scores on trauma norms 2022 (Zorginstituut Nederland, 2023b)

MTC	Score on volume norm[1]	Region	Score on 90% norm[2]
MST	306	AZEUR	88%
UMCG	350	AZNN	59%
Radboud UMC	502	AZO	81%
ETZ	412	NAZB	56%
Maastricht UMC+	260	NAZL	64%
VUmc	179	NAZNW[3]	49%
AMC	223	SZN[3]	66%
Isala	308	NAZZ	74%
LUMC	193	NAZW	88%
HagaZiekenhuis	104		
HMC	245		
Erasmus MC	426	TCZWN	63%
UMC Utrecht	353	NAZMN	75%

[1] Number of multitrauma patients that were treated at the MTCs in 2022

[2] Fraction of multitrauma patients who were directly transported to an MTC within each region in 2022

[3] Network Acute Care Northwest (NAZNW) and SpoedZorgNet (SZN) merged under one new name, Network Acute Care North-Holland/Flevoland (NAZNH-FL) in 2023

The analysis revealed that 9 out of the 13 MTCs meet the minimum volume norm of treating at least 240 multitrauma patients per year, with HMC slightly above the threshold. Except for the HMC, the MTCs situated in Amsterdam, The Hague and Leiden (AMC, VUmc, Hagaziekenhuis and LUMC) did not meet the norm. Situated in the western part of the Netherlands, which is densely populated, this region exhibits the lowest ratio of trauma patients to the population (Kramer & Leenen, 2022). This factor could be a contributing reason why these MTCs fail to meet the minimum volume norm. Another plausible explanation for this phenomenon could be that the MTCs are relatively close to each other, resulting in lower patient volumes distributed across each individual MTC (Meijer, 2022).

As for the 90% norm, none of the regions met the 90% norm in 2022. The best-performing regions were AZEUR and NAZW, with a score of 88%, while the worst-performing region was NAZNW, with a score of 49%. This indicates significant variation between regions. Possible reasons for lower scores on the 90% norm include the structure of the regional healthcare system, distance to the MTCs and the presence of MMTs from other regions (Sturms et al., 2021; Van der Erf et al., 2023). Trauma regions with more hospitals with emergency departments that are far from the MTC or longer average travel time to the MTC tend to score worse. Additionally, regions with fewer emergency departments and smaller travel distances to the MTC are more likely to bring multitrauma patients to the MTC by chance.

The presence of MMTs from other regions also affects the scores since multitrauma patients taken to an MTC outside the region by these teams do not count towards the 90% norm percentage for the region where the incident took place. The results of the structure of the regional healthcare system and the presence of MMTs from other regions came from a study conducted for the NAZB to explain the reasons behind the low score on the norm in this region (Van der Erf et al., 2023). This region has the most emergency departments open 24/7 and has one of the largest weighted average travel times to the MTC in the country. The MMTs of Radboud UMC and Erasmus MC also operate in this region, resulting in some multitrauma patients being taken to those MTCs instead of the ETZ, which does not count towards the 90% norm percentage for the NAZB. If these patients were included in the NAZB count, the region’s score on the norm would be 6% higher.

2.5 Stakeholders

The trauma care system involves many stakeholders, which can be defined as individuals, groups or organizations that are involved in or affected by the system. This report distinguishes between two types of stakeholders: direct and indirect.

Direct stakeholders are those who are directly involved in or affected by the trauma care system. The most important direct stakeholder is the trauma patient, as the primary goal of the trauma system is to provide the best possible care to trauma patients. Other essential direct stakeholders include all EMSs and associated personnel, as well as the dispatch centers that ensure that the right help arrives at the scene. Finally, MTCs and regional hospitals, along with their staff, are crucial direct stakeholders since they are responsible for providing care to trauma patients after the incident.

Indirect stakeholders, on the other hand, are those who are not directly involved or affected by the trauma system, but they have a stake in what happens in the system. An example of indirect stakeholders are the insurance companies, who are responsible for paying for the cost of care for trauma patients and therefore have a financial stake in the trauma care system (Rijksoverheid, n.d.). The government is also a significant indirect stakeholder, including the Ministry of Health, Welfare and Sport and governmental agencies like the National Health Care Institute (ZIN) and the Dutch Healthcare Authority (NZa). These parties have established the trauma norms, closely monitor progress and provide advice on meeting the norms (Zorginstituut Nederland, 2023a). Another organization that assists with this is the Dutch Association for Trauma Surgery (NVT), which aims to improve the quality of care for accident victims in the Netherlands. (NVT, n.d.) The LNAZ is another indirect stakeholder that supports acute care networks in the performance of their tasks, coordinates national projects and maintains the Dutch Trauma Registry (LNAZ, 2015). Additionally, researchers and academics in the field of trauma care are indirect stakeholders who investigate how trauma care can be improved in the future. They may collaborate with different stakeholders to improve existing trauma care practices or develop new ones.

2.6 Chapter summary

After an incident occurs, several processes are set in motion before the patient reaches the hospital. Choices need to be made regarding the deployment of the MMT and the mode of transportation. The Netherlands has various EMS types, with different characteristics, advantages and disadvantages. Hospitals are organized into different levels, with level I hospitals being considered as MTCs and level II and III as regional hospitals. The country is divided into 11 regional acute care networks, each with at least one MTC. However, 4 out of the 13 MTCs do not meet the minimum volume norm and no region meets the 90% norm in 2022. The trauma care system involves direct stakeholders such as trauma patients, EMS and associated personnel, dispatch centers, MTCs and regional hospitals. Indirect stakeholders include insurance companies, the government and organizations like the National Health Care Institute, the Dutch Healthcare Authority and the LNAZ.

3. Literature review

This chapter reviews existing literature focusing on models and factors that impact the prehospital care system and influence EMS mode selection. The review aims to provide insight into relevant studies and their findings to develop a predictive model for the Dutch prehospital trauma care system.

3.1 Models prehospital care system

Numerous research studies have been conducted to enhance the optimization of prehospital care systems, particularly concentrating on enhancing prehospital triage (e.g., Bouzat et al. (2015); Phillips and Buchman (1993)) and optimizing EMS allocation (e.g., Ingolfsson et al. (2008); Yin and Mu (2012)). Nevertheless, developing an effective model requires a thorough understanding of the various factors that impact the prehospital care system, including EMSs, hospitals, incidents, dispatch policies, travel models and transport modes. Therefore, it is essential to analyze existing literature studies and models, evaluate their strengths and limitations and select suitable components to construct a comprehensive model.

3.1.1 EMSs and hospitals

Emergency Medical Services and hospitals are crucial components of the prehospital care system. When modeling such systems, it is important to consider whether using a uniform approach is sufficient or if multiple classes or levels are necessary to reflect the various levels of care that patients may require. Morabito et al. (2008) conducted a study comparing different EMS approaches in practical applications. In the varied approach, ambulances were classified into advanced or basic support vehicles, contrasting the traditional approach of using only regular ambulances. The research findings suggest that the varied EMS approach provides greater detail and calibration, but it can be computationally time-consuming to come up with results. Discrete event simulation can be an alternative for evaluating large systems with this approach.

In contrast, hospitals are generally treated similarly in that they can treat any patient without making distinctions between them. However, in some models, certain patients must be transported to specific hospitals due to specialized facilities (Ridler et al., 2022). In the case of trauma care, this distinction is crucial as different levels of care are available at level I, II and III hospitals.

Capacity is also an important aspect to consider when modeling EMS and hospitals. Yin and Mu (2012) used finite capacity to ensure acceptable service levels and spatial equity, such as by placing a capacity constraint on the finite number of available ambulances for a maximal covering model. Assuming fixed capacity, the goal is to maximize performance with the available resources (Reuter-Oppermann et al., 2017). Additionally, a busy probability can be used to account for the likelihood that vehicles may be occupied and cannot immediately respond to a new incident (Erkut et al., 2008). Busy probabilities are crucial to ensure the system is not overloaded and can meet service-level targets.

Alternatively, in some studies, such as those conducted by Bekker et al. (2023) on Covid-19 hospital admissions and occupancy and Worthington et al. (2020) on queueing models of demand in healthcare, the assumption of infinite capacity is made to predict demand without the limitation of capacity constraints. Worthington et al. (2020) concluded that the concept of infinite capacity has already proven valuable in supporting healthcare resourcing decisions.

3.1.2 Incidents

Incident reports frequently lack completeness or consistency in how they are filled out. For instance, when recording the location of an incident, some individuals provide postal codes, while others specify coordinates or street names and some leave this information blank altogether. When data is incomplete, inconsistent or restricted due to privacy concerns, distributions are commonly used to generate incidents for a model. Kergosien et al. (2015) conducted a literature review of studies focused on ambulance location and relocation problems and found that a Poisson process and an exponential distribution are commonly used to model incident occurrence. In this context, the Poisson distribution is used to estimate the probability of a certain number of incidents occurring within a given period (Sharma et al., 2021). The exponential distribution, on the other hand, is a continuous probability distribution that is closely linked to the Poisson process, representing the time elapsed until the next incident occurs.

In practice, it may not be accurate to assume a constant intensity of incidents throughout the week. The reality is that the number of incident reports can vary significantly based on the time of day and the day of the week. For instance, there may be more incidents in the morning than in the evening and weekdays may have different intensities compared to weekends. To capture this variation, Bertsimas and Ng (2019) used different values per hour and day to represent the average hourly number of emergency calls in their ambulance deployment and dispatch study. Their analysis revealed that the afternoons generally had a higher number of calls, while the weekends had relatively fewer calls

If the locations of the incidents are unknown, they can be generated within the model in various ways. One approach is to consider all locations within the model as potential incident locations, but this can make it challenging to determine the travel times between the incident location, the EMS and the hospitals. Another method is to use discrete points such as the centers of postal codes. Shahriari et al. (2017) assumed that demand points were located in a square-shaped area where the length and width follow a uniform distribution. In contrast, Jagtenberg et al. (2015) defined a set of discrete points to represent demand locations, while Berke and Shi (2009) utilized postal centroids as potential incident locations. Demirtas (2016) took a different approach and used smoothing methods to create probability density functions of incidents from which one can sample as many discrete points as needed.

In situations where there is a finite number of available EMS vehicles and a call is made for an incident, all the available vehicles that can reach the patient in time may be already engaged. In such cases, it may be necessary to wait until a vehicle becomes available again. To represent this in a model, queues can be used where patients in the queue are served when a vehicle becomes available. The queue can be managed based on the first-come, first-served principle or priority can be given to patients who are likely more severely injured. Taylor and Templeton (1980) used the latter approach in their study about waiting time in a queue for urban ambulance service. Henderson and Mason (2004) also employed a similar approach, but in their study, incidents were divided into two priority groups and the first group was served before the second.

3.1.3 Dispatch policies

Once the incidents have been generated in the model, several factors come into play, including which vehicles are dispatched to the incident and the response time of the EMS to reach the scene and the distance to an appropriate hospital. Dispatch policies play a crucial role in these decisions.

The most commonly used dispatch policy, both in EMS organizations and the scientific community, is the nearest idle ambulance policy (Bélanger et al., 2019). This policy involves sending the closest available ambulance to respond to an emergency call. A variation of this policy is the regionalized response policy, as described by Swoveland et al. (1973). This approach prioritizes emergencies in the region of the ambulance and the nearest idle ambulance is dispatched only if there are no other available ambulances in the region. In contrast, Jagtenberg et al. (2017) utilized a heuristic approach for ambulance dispatching instead of the nearest idle ambulance policy. While this alternative reduced the fraction of late arrivals at the scene, it also increased the average response time.

While these studies typically focus on a single type of vehicle, there are instances where multiple types of vehicles are considered. For example, Lim et al. (2011) implemented a two-tier EMS system with priority dispatching. They had two types of ambulances available: one providing basic life support and the other offering advanced life support. Basic life support ambulances were dispatched for the majority of the emergency calls, reserving the advanced life support ambulances for high-priority calls. Another study by Olave-Rojas and Nickel (2021) incorporated call priority into their model. In addition to considering priority, their study allowed for the re-dispatching of ambulances to higher-priority emergency calls if they had not yet reached the patient of the original call.

Lastly, in the context of dispatch policies, it is important to consider the post-incident activities of the vehicles. Once their responsibilities with the patient are fulfilled, the vehicles can either return to their station, remain immediately available for subsequent patients or travel to other stations, as explored in the research conducted by Van Barneveld, Bhulai, et al. (2017). This immediate availability and relocation of vehicles contribute to reducing the response time for future emergency calls.

3.1.4 Travel models

When considering the travel distances of EMS vehicles, both towards the incidents and subsequently to appropriate hospitals, several important factors need to be taken into account within the model. These considerations aim to accurately represent real-world scenarios in the model. To determine the shortest driving distances, Hoedemaker et al. (2020) utilized the geometric centers of four-digit postal codes in the Netherlands, complementing the study by Berke and Shi (2009), who used postal code centroids as potential locations. The use of postal code centroids has been deemed an acceptable estimate of actual ambulance travel distance (Jarman et al., 2019).

Different methods that are often used to determine the distance between two points are the Manhattan and the Euclidean metric. Naoum-Sawaya and Elhedhli (2013) explored the Manhattan and Euclidean metrics in their stochastic optimization model for real-time ambulance redeployment. In cases where the road network resembles a rectangular grid, the Manhattan metric provides a more realistic estimate of travel distance compared to the Euclidean metric. However, the Euclidean metric can be suitable for estimating distances for helicopters, as they can fly in a straight line to incidents or hospitals without following road networks, as demonstrated by Chen et al. (2018) in their research on reducing prehospital time for trauma using helicopters. Alternatively, the haversine formula is used by Waalwijk et al. (2022), converting postal codes into latitude and longitude coordinates with OpenStreetMap to find the shortest distances between two points on a sphere. The advantage of the haversine formula is that it accounts for distances measured on a spherical surface, which is more accurate compared to measuring distances on a flat plane (Maria et al., 2020).

Furthermore, variations in circumstances such as traffic and weather conditions can impact travel times. Chen et al. (2018) incorporated historical weather and climate data, categorizing weather into different types such as clear, rain, hail, fog, thunderstorms and snow. They also considered peak and off-peak times for traffic conditions in their research. Metrot et al. (2019) employed two distance matrices, one for fluid traffic circulation and another for peak traffic times. Another approach to account for traffic during different times of the day is to incorporate grouped mean speeds for individual days of the week as Lupa et al. (2021) did in their case study on emergency ambulance speed characteristics. Notably, this study revealed that the average speeds of ambulances with sirens on remained relatively constant throughout the day, while speeds without sirens varied significantly.

3.2 Patient transportation modes

Helicopters and ambulances are the primary modes of transport used by EMS to transfer patients from incidents to hospitals. The decision regarding which vehicle to use for transport largely revolves around time and medical considerations. This study primarily focuses on the time aspect and does not assess the quality of care provided.

In 2021, in cases where patients had an ISS greater than 15, the ambulance was selected for hospital transport in 90% of instances, indicating a strong preference for ambulance transportation. When a helicopter is also available at the scene, the ambulance remains the choice for transportation in approximately 90% of such cases (Kramer & Leenen, 2022). This preference may be attributed to the limited space available for medical care during flights, as well as the typically short distances to appropriate hospitals in the Netherlands (Oude Alink et al., 2020). Studies based on historical data often reveal longer transport times for helicopter transportation compared to ambulances. This can be attributed to helicopters being used more frequently for transportation when the distances to appropriate hospitals are greater and the patients being transported by helicopter are often more severely injured, requiring more prehospital care (Butler et al., 2010; Pham et al., 2017; Stowell et al., 2019).

Currently, there is a need for an impact analysis concerning a potential increase in helicopter flights and the conditions for such deployments in the Netherlands (Zorginstituut Nederland, 2023a). Helicopters are primarily utilized for transport when they can save time compared to ambulances. However, determining when time can be saved is challenging as research on this topic has produced varying results. Previous studies conducted in the United States, Italy, Norway, France and Korea have reported distances ranging from 15 to 50 kilometers as the threshold where helicopters outperform ambulances (Brown et al., 2016; Diaz et al., 2005; Kim et al., 2017; Kristiansen et al., 2011; Paoli et al., 2020; Stowell et al., 2019). These distances are based on primary dispatches, where both the helicopter and ambulance are deployed simultaneously. Only one of these studies, Diaz et al. (2005), also considered secondary dispatches, indicating that a distance greater than 72 kilometers between the incident and the hospital favors helicopter transport. It is important to note that applying these findings to the Dutch system is challenging due to differences in the healthcare system, population density, road network and natural obstacles.

An advisory report from the National Health Care Institute suggests that when the estimated ground transport time to an MTC exceeds 30 minutes, the helicopter becomes the preferred option for patient transport (Zorginstituut Nederland, 2023a). This time-based threshold offers greater precision compared to using distance alone, as road conditions and other variables significantly influence travel time in ground vehicle transport scenarios. Incorporating geographic information systems (GIS) into the analysis provides a more precise assessment of travel time differences between helicopters and ambulances. Lerner et al. (1999) used GIS in their research, identifying different distances in various regions surrounding a trauma center where helicopters were more beneficial. Jang et al. (2021) and

Widener et al. (2015) utilized GIS to retrospectively review helicopter transports and predicted ambulance travel times for the same patients, enabling a more precise estimation of the travel time difference. These studies concluded that GIS offers great potential in evaluating how time and distance contribute to patient outcomes and that the benefit of using helicopters increases as the distance to an appropriate hospital grows.

3.3 Limitations

The existing literature has some limitations in the discussion of prehospital transportation, highlighting areas that are rarely explored. One area that remains largely unexplored is the understanding of specially equipped priority vehicles in scenarios where helicopters cannot be employed within prehospital care models. Existing models predominantly focus on ambulances and helicopters, leaving the specially equipped priority vehicle underrepresented in research and analysis.

Furthermore, prehospital transportation models often overlook the consideration of different hospital levels and varying severity of injuries, aspects that are crucial in trauma care. The focus of the existing models is also mainly on ambulance location and relocation problems, while this research tries to present a comprehensive prehospital process and conduct practical experiments.

Moreover, traffic and weather conditions are not frequently integrated into existing models, assuming static and unchanging conditions throughout the transportation process. However, these dynamic conditions can influence the process within the model. By incorporating factors like deviation, it becomes possible to partially account for these influences in the model. Additionally, adapting assumptions from existing models to the Dutch context can be challenging due to substantial differences in the trauma care system, contextual factors and underlying assumptions.

Another limitation lies in the scarcity of logistical guidelines for determining when to use ambulances or helicopters for patient transport. The existing studies in this area offer varying results and lack definitive rules, which suggests that these guidelines are situation-dependent. Lastly, the use of distance-based criteria as guidelines for when a helicopter should be used for transport is limiting. A more effective approach would involve incorporating GIS data, which accounts for the location of the incidents and the different road types.

3.4 Chapter summary

This chapter delves into the optimization of prehospital care systems, examining key components such as EMSs, hospitals, incidents, dispatch policies, travel models and transport modes. EMSs and hospitals play a central role in this system, where flexible approaches are often required. Studies have explored the categorization of ambulances into different classes to provide specialized care, although this can be computationally demanding. Hospital differentiations are crucial for effective trauma care, alongside capacity considerations and busy probabilities to maintain service levels.

Challenges in acquiring incident data arise from inconsistencies in reporting. Researchers often use Poisson processes and an exponential distribution to model incident occurrences, but accounting for variations based on time is essential as incident rates fluctuate by time of day and day of the week.

Dispatch policies significantly influence response times, with the nearest idle ambulance policy being common. Post-incident activities like immediate availability and relocation contribute to reducing response times. Travel models factor in driving distances, road networks and weather conditions, employing metrics like Manhattan and Euclidean, with Geographic Information Systems (GIS) enhancing accuracy.

Patient transport decisions between ambulances and helicopters hinge on time and medical considerations, with ambulances chosen in around 90% of cases, even when a helicopter is available at the scene. Assessing the impact of increased helicopter deployment in the Netherlands is complex, with studies suggesting varying optimal distances (15-50 km) compared to ambulances. An advisory report recommends helicopters when ground transport exceeds 30 minutes, accounting for variables like road conditions.

However, limitations exist in the current literature, including underrepresentation of priority vehicles, insufficient consideration of hospital levels and injury severity and often overlooking traffic and weather conditions. Clear guidelines for choosing between ambulances and helicopters are scarce. Relying solely on distance-based criteria to decide on helicopter use is restrictive, emphasizing the need to incorporate GIS data. During the development of the model, these challenges and limitations will be considered and incorporated into the model. The next chapter will elaborate on this process, providing insights into all other choices and aspects crucial to the model.

4. Model

This chapter provides an exploration of the developed simulation model, including the reason for the type of modeling and its usage. It discusses the parameters and variables involved, along with an explanation of the underlying assumptions and simplifications. The chapter concludes with a description of the model's functionality and operational process.

4.1 Model scope

Choosing an appropriate model for the research objectives is crucial and Discrete Event Simulation (DES) stands out for compelling reasons. DES offers efficiency when dealing with data-intensive systems like the prehospital trauma care system and delivers results within short time frames (Ünlüyurt & Tunçer, 2016). Its user-friendly application simplifies model creation, modification and analysis, especially crucial when frequent scenario testing is required. Furthermore, DES provides valuable visual insights, enabling close monitoring of EMS and patient movements, pinpointing potential model errors, streamlining processes and ensuring the simulation model's accuracy. In essence, DES aligns seamlessly with the goals and requirements of this research, guaranteeing a robust and efficient approach.

The simulation model aims to assess the potential outcomes of achieving trauma norms compared to the current state by testing a range of potential future scenarios and evaluating their impact on the prehospital trauma care system. This involves all processes from incident occurrence to patient hospitalization. The model includes trauma patients transported via ambulance or helicopter in 2022, excluding those with self-transport. This exclusion amounts to approximately 25% of all trauma patients and 5% of multitrauma patients (Kramer & Leenen, 2022). To present a comprehensive view of the entire trauma patient group, including those who self-transported, an increase of 5% is required for multitrauma patients and 24.85% for trauma patients across the model output. Notably, since the model only considers 95% of multitrauma patients, an MTC is considered to meet the minimum volume norm by treating a minimum of 228 multitrauma patients (240*0.95) rather than the original 240. The model's validity is tested by simulating the current situation before applying adjustments to align with the trauma norms. A deviation of up to 5% between the simulation model's output values and actual values is deemed acceptable for validation purposes.

The simulation model strives to closely mirror real-world conditions by incorporating stochasticity, which introduces non-deterministic characteristics into specific variables. Additionally, the model incorporates various aspects of ambulance and MMT operations. Concerning ambulance operations, it is accounted that certain stations are not operational 24/7, necessitating closures during specific times of the day. Furthermore, the model accommodates scenarios like resuscitation cases, which may demand the dispatch of a second ambulance for an incident.

Turning to MMTs, each station is equipped with both a helicopter and a ground vehicle, except for the German teams, which exclusively utilize the helicopter. To accurately reflect the logistical constraints inherent in real-world MMT operations, the model ensures that a station's helicopter and ground vehicle cannot be simultaneously deployed. Moreover, as previously highlighted, German helicopters are limited by their lack of night vision capabilities, rendering them inoperative between sunset and sunrise. Additionally, it is essential to note that the ground vehicle is not designated for patient transport. These considerations collectively contribute to a model that mirrors the nuanced complexities and operational constraints inherent in prehospital trauma care systems. Unfortunately, in the realm of simulation modeling, achieving absolute comprehensiveness is an elusive goal. Consequently, certain situations require the formulation of assumptions, a necessity that will be elaborated later on in this chapter.

4.2 Model design

In our model, certain assumptions are adopted, notably, the assumption of infinite hospital capacity and finite EMS capacity. The reasoning behind these choices is that infinite hospital capacity aids in predicting potential demand during scenario testing, while finite EMS capacity is required to determine the busyness of the vehicles. Additionally, different levels of hospitals are incorporated into the model to distinguish between MTCs and other hospitals. Within the EMS, ambulances, helicopters and ground vehicles are considered to comprehensively address the spectrum of services. Despite their underrepresentation in current literature, this research's model includes ground vehicles, different hospital levels and varying injury severity. Furthermore, the inclusion of busy probabilities enhances the model's realism by accounting for EMS utilization in cases unrelated to trauma care.

To generate incidents in the model, a commonly used approach to model incident occurrence is employed. This involves utilizing the exponential distribution, which describes the time intervals between random events within a Poisson process (Kergosien et al., 2015). Additionally, the time of day is taken into account when generating these incidents. For incident locations, postal code centroids are utilized to divide the country into roughly 4,000 non-overlapping regions, simplifying the calculation of travel times. The use of discrete points as incident locations aligns with established travel models (Jagtenberg et al., 2015). To determine distances between these points for helicopter routes, the Euclidean metric is employed. For estimating actual driving times between postal codes, there is access to data from Object Vision (2019), enabling the identification of the fastest driving routes.

Some of the travel models found in the literature incorporated variables like traffic and weather conditions to capture real-world variation. To account for these variations, deviations in travel times and a probability factor for helicopter unavailability due to adverse weather conditions are introduced within the model. For the dispatch policy, the nearest available ambulance approach is considered. Furthermore, vehicles are allowed to be dispatched immediately after completing their current patient transport, striving to mirror real-world scenarios as closely as possible.

To represent the current real-world situation within the model, percentages are incorporated to depict the frequency with which Dutch and German helicopters transport trauma patients when they are available at the incident. However, it is worth noting that the choice of specific distances or times as thresholds remains a subject of ongoing debate within the field. As a result, using these values in the model may lead to either an over- or underestimation of helicopter transports.

4.3 Assumptions and simplifications

To handle complexity and ensure computational feasibility and comprehensibility, the model incorporates various assumptions and simplifications. Despite these considerations, the model aims to provide accurate and valid results. These assumptions and simplifications can be categorized as follows: patients, hospitals, ambulances, MMTs and others.

Patients

1. Each patient belongs to a separate incident.
2. The arrival of patients follows a Poisson distribution, which varies according to the time of day.

In reality, accidents like car accidents may involve multiple individuals. However, this model simplifies the scenario by assuming that only one person is involved in each accident. The incident rate follows a Poisson distribution, which varies based on the time of day. The model generates a higher proportion of incidents in the afternoon and evening compared to the morning and night, aligning with the known ratios provided by the LNAZ (Kramer & Leenen, 2022).

Hospitals

3. The model treats level II and III hospitals without differentiation.
4. Hospitals lacking a 24/7 emergency room are assumed to operate from 8:00 AM to 9:30 PM.
5. The hospitals have infinite capacity.

The model does not distinguish between level II and III hospitals, as its primary focus is on trauma norms. Whether a multitrauma patient is admitted to a level II or III hospital does not affect the model's analysis. Hospitals without a 24/7 emergency room are assumed to operate 8:00 AM to 9:30 PM, based on the current opening hours of the specific hospitals, with an average value utilized for simplicity. Infinite capacity is assumed for hospitals to ensure the constant availability of beds for multitrauma patients.

Ambulances

6. Ambulance dispatch levels are categorized as either A1 or A2.
7. During A2 deployment, ambulances travel at the same speed as regular cars, while A1 deployment allows them to be 35% faster toward an incident location.
8. During A1 deployment, ambulances travel 20% faster than regular cars from the incident location to the hospital.
9. Ambulances within RAVs are evenly distributed across the stations.
10. Ambulances are dispatched only within their respective RAV unless all ambulances within that RAV are already engaged.
11. The model accounts for non-trauma-related ambulance deployments by considering a busy probability.

The ambulance deployments in the model are categorized as A1 or A2, excluding B rides, which are plannable rides in real life. It is assumed that A2 dispatches drive at the same speed as regular cars, operating without sirens, unlike A1 dispatches. The assumption that ambulances drive 35% faster during A1 deployments is based on a study by Meijer (2022), which found this percentage to be a good reflection of reality. It is important to mention that while an ambulance during an A1 deployment continues to maintain a faster pace than a regular car when traveling from the incident location to the hospital, it does drive slightly slower when traveling toward the hospital. Adjusting the transportation time within the model in this way ensures a closer alignment with the transportation times indicated in the data (Ambulancezorg Nederland, 2023). This decision acknowledges that delivering medical attention at higher speeds can pose greater challenges.

Information about the number of ambulances stationed at each station is unavailable, but the model distributes them evenly across the stations within an RAV based on the known total number of ambulances in the various RAVs (Ambulancezorg Nederland, 2023). For instance, if there are 11 ambulances in a RAV with 10 stations, each station receives one ambulance and the extra ambulance is allocated to the station in the postal code area with the highest population. These ambulances are primarily deployed for incidents within their respective RAVs unless all ambulances within an RAV are already occupied.

Lastly, the model considers ambulance deployments that are not trauma-related. Although these deployments are not explicitly reflected in the model, a busy probability estimate is used to determine whether an ambulance can be deployed or if it is currently occupied with non-trauma-related matters beyond the scope of this model.

MMTs

12. The Belgian HEMS is not considered in the model.
13. Similar to A1 deployments, ground vehicles operate 35% faster than regular cars.
14. All dispatches are treated as primary dispatches.
15. Non-trauma-related MMT deployments are accounted for using busy probability.
16. The model incorporates an unavailability probability to address instances where the helicopter cannot be deployed due to maintenance or bad weather.

The Belgian HEMS is not included in the model because of its limited operation within a small region of the Netherlands. Additionally, the ground vehicle is assumed to travel at a speed comparable to that of an ambulance during an A1 deployment. All MMT dispatches in the model are considered primary dispatches. This implies that the MMT is deployed only at the moment the incident is reported, while in reality, the MMT can also be deployed secondarily after the first medical aid is at the scene.

Similar to the ambulances, the model incorporates a busy probability to account for non-trauma-related cases that fall beyond its scope. Furthermore, the ground vehicle may need to be deployed when the helicopter is undergoing maintenance or during adverse weather conditions when flying is not possible. In such cases, the model utilizes probability to determine the appropriate course of action.

Others

17. If the helicopter is selected as the means of transport, the patient is always transported to an MTC.
18. The duration of the response, treatment and handover times follow a gamma distribution with specified alpha and beta values.
19. The ISS and whether the patient will be transported to an MTC are pre-determined when the incident is generated.
20. The model excludes the Wadden Islands from consideration.

If a helicopter is utilized for transportation, the patient is always taken to an MTC. This presumption is based on the understanding that helicopter transport is reserved for cases of significant injury. Regarding process durations, such as response, treatment and handover time, a gamma distribution is assumed. An explanation of why this distribution is assumed can be found in Appendix A. Values for the shape (α) and rate (β) parameters have been derived from available data for each of these processes. Upon incident generation in the model, the patient is immediately assigned an ISS and a determination is made whether transport to an MTC is necessary. However, in reality, the ISS can only be determined after the patient reaches a hospital.

Furthermore, the mode excludes the Wadden Islands. In actual practice, most patients on the Wadden Islands are transported by an ambulance helicopter from Leeuwarden (ANWB, 2017). As this ambulance helicopter is not included in the model, it is reasonable to exclude the Wadden Islands due to their low population.

4.4 Parameters and variables

The model's parameters and variables are introduced, starting with the input used by the model. Subsequently, the variables for the different entities within the model are presented.

4.4.1 Input model

The model integrates a wide range of data concerning patients, EMS, hospitals, postal codes, distances, driving times and time-related aspects. Patient data includes the number of patients, the percentage with specific ISS, the percentage transported to MTCs and prehospital process durations, sourced from the national trauma registration data of the LNAZ for 2021 and 2022.

For EMS, the model considers stations open in 2021 and the available number of vehicles. Accounting for some non-24/7 stations, the model takes into account that these stations are closed for some parts of the day. Regarding hospitals, all emergency room-equipped facilities in the country are included. However, four hospitals without 24/7 ERs are accounted for within the model.

Postal code input entails x and y coordinates of postal code centers, population counts and postal codes linked to care regions (ROAZ) and ambulance regions (RAV). The x and y coordinates are utilized to calculate the Euclidean distance between various postal codes, essential for determining the distances the helicopters must travel between different points. Flight speed over these distances varies with helicopters building up more speed over longer distances. The model incorporates the minimum and maximum speed the helicopter can reach. A study conducted in collaboration with RIVM and the MMTs in the Netherlands utilized the following formula (Zwakhals et al., 2008):

$$Speed = \mathrm{b} + \mathrm{a} * \log(distance) \ \ in\ km/h$$

$$Distance\ is\ in\ km$$

$$With\ minimum\ and\ maximum\ speed$$

Parameter “b” represents a ‘delay’ in the speed to be achieved and parameter “a” is a scaling factor. To estimate real driving times between postal codes, data from Object Vision (2019) is used, allowing the identification of the fastest driving routes between the postal codes.

The model also considers different parts of the day and factors in sunrise and sunset. A report by the LNAZ reveals that a higher proportion of incidents occur in the afternoon and evening compared to the morning and night (Kramer & Leenen, 2022). To incorporate these ratios, the model adopts specific time limits for different parts of the day: morning (8 AM), afternoon (noon), evening (5 PM) and night (midnight). Additionally, the model accounts for German helicopters' operational hours by using sunset and sunrise values, ensuring flights do not occur between these times.

4.4.2 Entities

The model consists of various entities in motion, including patients, ambulances, helicopters, ground vehicles of the MMT and HEMS physicians. Each entity possesses its set of variables, some of which are initialized at the start, others obtained during the process and some subject to changes throughout.

The patients' variables, as depicted in Table 4, include the incident's date, time and postal code location. Subsequently, an ISS is assigned to the patient based on the nearest MTC. This is done because in some regions around the MTCs the ratio of trauma to multitrauma is higher (AZEUR, 2023). Additionally, the model determines the appropriate ambulance dispatch level and whether an MMT is required. A probability is calculated for patients with an ISS greater than 15 to determine whether they will be transported to an MTC, based on the location of the incident. Next, the model assigns the necessary vehicles to the patient for the provision of care. Treatment time at the incident location is calculated based on the patient's ISS, followed by selecting the transportation mode and the destination hospital.

Table 4: Patient variables

Patient	
Variable	**Type**
Day of incident	Integer
Time of incident	Time
Postal code incident	Integer
Patient label	Integer
ISS category	String
Dispatch level ambulance	String
MMT deployed to incident	Boolean
Patient to MTC	Boolean
Ambulance to patient	Object
Additional ambulance to patient	Object
Helicopter to incident	Object
Ground vehicle to patient	Object
Treatment time	Time
Transport mode	String
Hospital	String

For ambulances, as outlined in Table 5, the model initially determines their station, corresponding postal code and the RAV where they operate. During the simulation, the ambulance's availability for deployment is recorded, noting whether it has already been assigned to a patient at a specific time. When the ambulance is assigned to the patient, this information is registered and upon completing all necessary tasks for the patient, the patient is disconnected from the ambulance.

The model keeps track of the ambulance's journeys by recording the departure and arrival postal codes each time it moves. As the ambulance travels, these variables are updated. Moreover, the model can estimate the ambulance's current location based on its start and end points, along with the expected travel time between postal codes.

The ambulance's response time comprises the triage time from the control room and the ambulance's start-up time, determined by its dispatch level. In cases where both the ambulance and the MMT are deployed and the ambulance serves as transport, the physician from the helicopter or ground vehicle accompanies the ambulance to the hospital. Lastly, the model calculates the handover time required for the ambulance to transfer the patient to the appropriate location in the hospital.

Table 5: Ambulance variables

Ambulance	
Variable	**Type**
Station	String
Postal code station	Integer
RAV	String
Deployable	Boolean
Assigned to patient	Object
Travel from	Integer
Travel to	Integer
Current location	Integer
Start time travel	Time
Expected travel time	Time
Response time	Time
Assigned HEMS physician	Object
Handover time	Time

For both the helicopters and ground vehicles, represented in Table 6, common variables are shared, allowing them to be discussed collectively. Each vehicle has a name or title and the postal codes of their stations are determined at the start. At each station, a physician is shared between the available helicopter and ground vehicle and the physician is coupled to the vehicle when it is deployed for a patient.

Similar to ambulances, the model keeps track of the vehicle's availability, monitors the designated patient, determines the start and end points of the journey, estimates the current location using start and expected travel time and calculates the response time. However, one notable difference between helicopters and ground vehicles is that the helicopter can also be used to transport patients. Consequently, the helicopter includes an additional variable for the handover time, which accounts for the time required to transfer the patient.

Table 6: Helicopter and ground vehicle variables

Helicopter / Ground vehicle	
Variable	**Type**
Title	String
Postal code station	Integer
HEMS physician	Object
Deployable	Boolean
Assigned to patient	Object
Travel from	Integer
Travel to	Integer
Current location	Integer
Start time travel	Time
Expected travel time	Time
Response time	Time
Handover time (only helicopter)	Time

Lastly, the HEMS physician is an integral part of the team dispatched to the incident either by helicopter or ground vehicle. Within the model, as illustrated in Table 7, the postal code of the station from which the team is operating is documented and the physician is linked to a specific vehicle. Throughout the process, the physician's location is monitored, whether they are with the helicopter, ground vehicle or accompanying the ambulance.

Table 7: HEMS physician variables

HEMS physician	
Variable	**Type**
Postal code station	Integer
Assigned HEMS	Object
Located at HEMS	Boolean

4.5 Model explanation and functionality

Figure 5 illustrates the core logic of the simulation model, featuring six sub-processes displayed on the left side of the figure (indicated by blue boxes with white text). More comprehensive flow charts of these sub-processes are available in Appendix B.

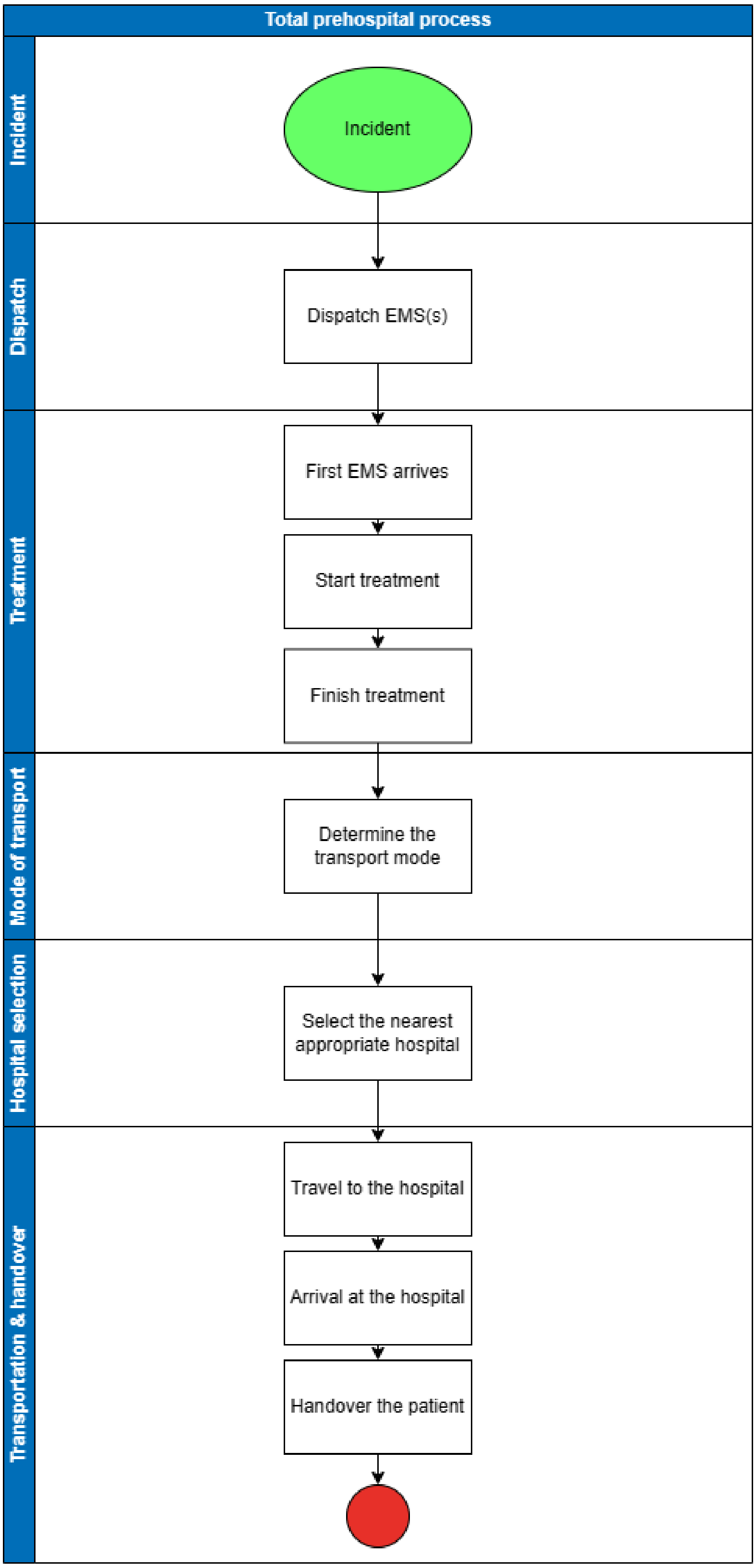


Figure 5: Flow chart of the high-level process in the simulation model

The model generates incidents using the Poisson distribution, considering the time of the day. Incident locations are determined based on the population numbers in various postal codes and the number of trauma patients in different ROAZ regions. Consequently, incidents are more likely to occur in densely populated areas and regions with a higher number of trauma patients. Each patient is then assigned an ISS, required ambulance dispatch level and potential MMT need, based on probabilities. These probabilities account for factors such as patients with a higher ISS being more likely to require an MMT dispatch. Subsequently, a decision is made regarding whether the patient should be transported to an MTC. The region of the incident influences this decision, as some regions send patients faster to MTCs, especially for patients with higher ISS values.

After determining patient and incident details, the appropriate EMS response is analyzed. Typically, a single ambulance suffices, but an MMT or a second ambulance may be required, especially in resuscitation cases. All available ambulances within the RAV of the incident are evaluated to select the fastest response. The busy probability is also applied to determine whether an ambulance can be deployed or if another ambulance is necessary. Similarly, for MMTs, both the helicopter and the ground vehicle are examined, with an extra check to determine if the helicopter can be deployed or whether the ground vehicle of that station must be deployed instead.

Once the closest available vehicles are selected, they head to the incident site. Treatment begins upon the arrival of the first EMS, with treatment times adjusted based on the patient's ISS, allowing for longer treatment for patients with higher ISS values. The appropriate vehicle for patient transport is also determined. If only an ambulance or an ambulance with a ground vehicle is dispatched, the ambulance is chosen for transport. However, when both an ambulance and a helicopter are dispatched, a probability factor is applied to decide on the transport vehicle, with a notable preference for the ambulance when a Dutch helicopter is available. If an MMT is present at the incident and the ambulance is used for transportation, the helicopter's or ground vehicle's physician accompanies the ambulance.

After determining the appropriate transportation vehicle, the next step involves selecting the nearest suitable hospital for the patient's transport. At the beginning of the process, it is already determined whether the patient should be transported to an MTC or a different hospital. If the patient requires transport to an MTC, the nearest MTC is identified. For other patients, the model searches for the closest hospital. There is a possibility that a multitrauma patient, initially deemed not to be taken to an MTC, ends up at the nearest MTC due to its proximity. In cases where helicopters or ground vehicles are not used for transport, they head toward the designated hospital to retrieve their physician.

Ambulances that are not selected for patient transport are returned to their stations and made available for the next incident. Even if the vehicle has not yet reached the incident, it is considered canceled and sent back to its station. The model's capacity to estimate the current location of the vehicles allows for the possibility of using a vehicle for a subsequent incident if it appears to be the closest available one before returning to its station.

Upon arrival at the hospital, the patient is handed over and all relevant patient information is recorded. The model efficiently tracks the data related to hospitals, different ROAZ and RAV regions and the status of the vehicles. If a HEMS physician is present with an ambulance, they will rejoin the helicopter or ground vehicle they originally came from. Following that, all vehicles return to their respective stations, becoming available again for other incidents.

The simulation itself commences at midnight and spans 365 days, corresponding to the yearly evaluation cycle of the trauma norms. Before launching the simulation, a preliminary verification step ensures that all stations and hospitals not operational at night remain closed during appropriate hours. Upon successful completion of this verification, the simulation process is set into motion.

4.6 Key Performance Indicators

The model tracks data related to hospitals, different ROAZ and RAV regions and the EMS' vehicles. This data serves as a basis for comparing various scenarios and their potential impact on the trauma care chain. Given the complexity of examining numerous aspects, the focus is on key performance indicators (KPIs) that represent the most crucial factors.

For hospitals, the tracked indicators include the number of multitrauma, trauma and total patients. Particularly important is the count of multitrauma patients at each MTC, as it helps assess compliance with the volume norm. This count becomes a KPI showcasing how different scenarios affect adherence to the minimum volume norm.

Like hospitals, the tracking within the ROAZ regions includes the count of multitrauma, trauma and total patients. Furthermore, it observes the multitrauma patients' arrival at MTCs and non-MTC hospitals and the presence of regular trauma patients at MTCs. These figures are crucial for calculating the score on the 90% norm and the under- and overtriage rates. This research is heavily guided by the 90% norm, complementing the volume norm, and this marks it as a crucial KPI.

For the RAV regions, the data also included the multitrauma, trauma and total patients. Furthermore, the average times of processes are recorded, differentiated between multitrauma and regular trauma patients. This involves average response time, on-scene time, transportation time and total prehospital time for both types of patients. Derived from the total prehospital times, the analysis assesses the proportion of patients reaching the hospital within 45 and 60 minutes from the incident report. Additionally, the deployment frequency of a second ambulance in the RAV regions for incidents is analyzed and the average busyness of the ambulances within each RAV is monitored.

The total prehospital time, along with the proportion of patients reaching the hospital within 45 and 60 minutes are seen as KPIs. In the medical field, the term "golden hour" is familiar to EMS personnel and trauma surgeons. This concept indicates that an injured patient has a window of 60 minutes from the time of injury to receive definitive care, beyond which the risk of morbidity and mortality significantly increases (Rogers et al., 2015). Moreover, the transportation time to the hospital is regarded as a KPI. This is because it plays a role in determining the patient's hospital destination and it may vary, particularly if there is a shift towards transporting more patients to MTCs. Research indicates that with increased distance from the incident to an MTC, EMS personnel are more inclined to transport patients to closer non-MTC hospitals rather than the nearest MTC (Zorginstituut Nederland, 2023a).

Lastly, EMS data is categorized into ambulances and HEMS. Their deployment frequency, along with the number of A1 and A2 ambulance deployments and helicopter/ground vehicle deployment for HEMS, is tracked. The model examines MMT utilization for all patients and ambulance and helicopter transportation frequencies. To gain meaningful insights from the number of helicopter transports alone, the proportion of helicopter usage for transportation is monitored, specifically when the helicopter is present at the incident.

Furthermore, vehicle cancellations based on time are examined. If multiple vehicles are dispatched for a patient and the first vehicle reaches the patient, performs treatment and is ready for patient transport, the remaining vehicles yet to arrive at the scene are considered canceled. Finally, the average busyness of the vehicles is determined. A vehicle is considered busy from the moment it is deployed for a patient until it is no longer needed for the patient or if the patient has been handed over at the hospital. This busyness metric is employed as one of the KPIs, providing insights into whether the vehicles, on average, experience longer or shorter durations during changes in the experiments. The last KPIs considered are the percentage of canceled MMT deployments and the fraction of patients transported by helicopter when the helicopter is available. This can, for example, help examine if a higher percentage of flights are canceled with increased deployments and whether the helicopter is more frequently used for patient transportation.

A comprehensive summary of all the KPIs is presented in Table 8.

Table 8: KPIs

KPIs	Related to
Number of multitrauma patients at each MTC	MTCs
Score on the 90% norm of each ROAZ region and nationwide	ROAZ regions
Average transportation time for trauma and multitrauma patients	RAV regions
Average total prehospital time for trauma and multitrauma patients	
Fraction of trauma and multitrauma patients with a total prehospital time below 45 minutes	
Fraction of trauma and multitrauma patients with a total prehospital time below 60 minutes	
Average busyness of the ambulances and HEMS	EMSs
Fraction of cancellations based on time for the HEMS	
Fraction of times a helicopter was used for transport when the helicopter was present	

4.7 Validation

To validate the model, comparing the model's output with real-world values is crucial. As previously mentioned, patients who arrived at the hospital through self-transport are not considered in the model. To account for this, 5% of multitrauma patients and 24.15% of the total patient group are excluded from the base model.

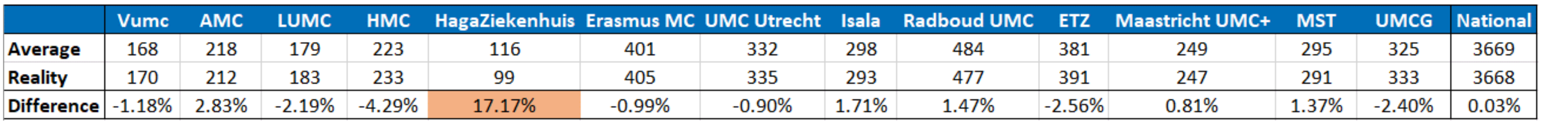
The model's validity assessment comprises 18 simulation runs of the current situation, conducted before any adjustments to align with trauma norms. For additional insights into the utilization of 18 simulation runs in the model's validation and a more detailed explanation of the validation procedure, refer to Appendix C. A deviation of up to 5% between the model's simulated outputs and actual data is considered acceptable for validation purposes. The average outcomes from these 18 simulation runs are then compared with real-world data and the differences are documented.

Specifically, the differences are outlined in Table 9 for the score on the 90% norm and Table 10 for the count of multitrauma patients at each MTC. Notably, differences consistently fall below the 5% threshold, with an exception observed in the count of multitrauma patients in the HagaZiekenhuis. This difference arises because the NAZW region has multiple MTCs in close proximity. The model accounts for the nearest MTC, while actual cases may involve transport to another nearby MTC, like the HMC and the LUMC, due to their relative proximity. However, when aggregating the multitrauma patient figures for this region, the variation diminishes to less than 5% when compared to actual values, as evident in Table 11.

Table 9: Differences between model and reality - score on 90% norm

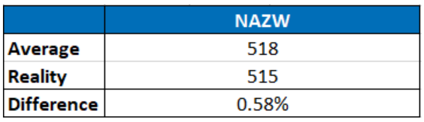
	NAZNW	SZN	NAZW	TCZWN	NAZMN	NAZZ	AZO	NAZB	NAZL	AZEUR	AZNN	National
Average	49.71%	66.57%	85.96%	62.88%	77.14%	74.76%	78.68%	57.56%	62.44%	87.74%	60.95%	69.49%
Reality	49%	66%	88%	63%	75%	74%	81%	56%	64%	88%	59%	70%
Difference	1.45%	0.86%	-2.32%	-0.18%	2.85%	1.03%	-2.87%	2.79%	-2.44%	-0.29%	3.31%	-0.73%

Table 10: Differences between model and reality - multitrauma patients at each MTC



	Vumc	AMC	LUMC	HMC	HagaZiekenhuis	Erasmus MC	UMC Utrecht	Isala	Radboud UMC	ETZ	Maastricht UMC+	MST	UMCG	National
Average	168	218	179	223	116	401	332	298	484	381	249	295	325	3669
Reality	170	212	183	233	99	405	335	293	477	391	247	291	333	3668
Difference	-1.18%	2.83%	-2.19%	-4.29%	17.17%	-0.99%	-0.90%	1.71%	1.47%	-2.56%	0.81%	1.37%	-2.40%	0.03%

Table 11: Aggregating multitrauma patients in NAZW

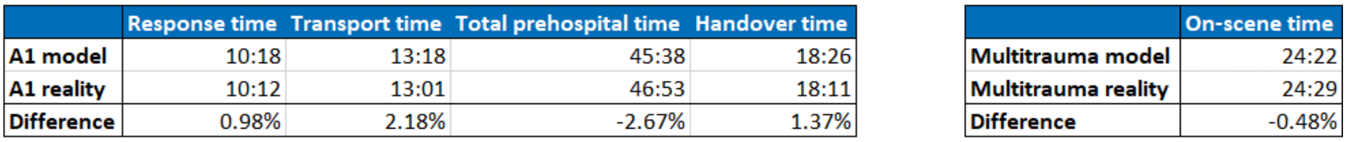


	NAZW
Average	518
Reality	515
Difference	0.58%

For the prehospital time intervals, the comparison involves the average intervals and data from Ambulancezorg Nederland (2023), displayed in Table 12 and Table 13. This data corresponds to information about A1 and A2 ambulance deployments. The comparisons indicate that the model generally aligns well with real-world data, with differences staying within a 5% range between the simulated outputs of the model and the actual data, except for the transport time of A2 deployments. In this case, the model slightly overestimates the transport time compared to actual values. It is important to note that, within the model, A2 deployments are limited to certain non-multitrauma cases, while A1 is consistently deployed for multitrauma patients.

On-scene times, on the other hand, were not compared to Ambulancezorg Nederland data but were instead assessed using data from the LTR. This decision was made due to the LTR data's focus on trauma patients, allowing for more accurate estimates. Unlike the A1 and A2 deployment comparisons, this evaluation was conducted with multitrauma and trauma patients. The values from the model closely align with reality, which is expected since this LTR data is an input for the model.

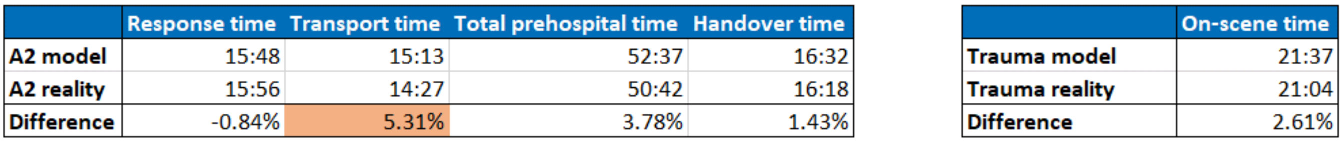
Table 12: Comparison prehospital time intervals A1 deployments and multitrauma patients in minutes



	Response time	Transport time	Total prehospital time	Handover time
A1 model	10:18	13:18	45:38	18:26
A1 reality	10:12	13:01	46:53	18:11
Difference	0.98%	2.18%	-2.67%	1.37%

	On-scene time
Multitrauma model	24:22
Multitrauma reality	24:29
Difference	-0.48%

Table 13: Comparisons prehospital time intervals A2 deployments and trauma patients in minutes



	Response time	Transport time	Total prehospital time	Handover time
A2 model	15:48	15:13	52:37	16:32
A2 reality	15:56	14:27	50:42	16:18
Difference	-0.84%	5.31%	3.78%	1.43%

	On-scene time
Trauma model	21:37
Trauma reality	21:04
Difference	2.61%

4.8 Chapter summary

The chapter introduces a realistic simulation model that considers incident generation, dispatch decisions, transportation options and hospital selection. The simulation incorporates realistic elements, such as a Poisson distribution for incident generation, gamma distributions for process durations and regional influences on transport decisions. The model also accounts for MMT deployment and their availability based on a busy probability, similar to the ambulances. It comprehensively simulates the entire EMS workflow, from incident initiation to patient handover at the hospital. The outlined assumptions and simplifications ensure computational feasibility and accuracy in delivering valid results. The model's output is validated against real-world values.

5. Experimental design

This chapter provides insights into the experiments that have been conducted. It begins with an explanation of the relevance of these experiments to the prehospital trauma care system and the challenges mentioned in the problem cluster. Following this, different experiments are tested to observe their effects on the overall system and a sensitivity analysis is performed.

5.1 Experiments

The analysis of various experiments centers on potential future scenarios or areas of interest to comprehend their potential impacts. Below, the different experiments are presented along with an explanation of their specific details and characteristics.

1. Achieving 90% norm

One notable experiment revolves around assessing the outcomes if all regions achieve the 90% norm. Presently, the national score stands at around 70%, with regional scores ranging from 49% to 88%. The significance of achieving this norm lies in the increased likelihood of improved outcomes and survival for multitrauma patients, as specialized care can be provided within the MTCs. The aim is to achieve the nationwide 90% norm by 2025 and strategies to enhance the score are currently under examination. This involves situations like prioritizing transportation to an MTC, even if it's farther than a non-MTC hospital and employing a trauma triage app to assist ambulance professionals in better estimating whether a patient is a multitrauma case or not (Zorginstituut Nederland, 2023a). To ensure each ROAZ region meets this norm, this experiment involves increasing the changes of transporting each patient labeled as a multitrauma patient in the model to an MTC. This experiment will evaluate the effect of having near-perfect triage.

2. Overtriage 50%

In this experiment, the objective is to address the challenge of accurately assessing incident severity at the scene, where the ISS cannot be used to identify multitrauma patients initially (Newgard et al., 2008). The objective is to increase the frequency of patient transportation to an MTC when there exists real-world uncertainty regarding the necessity of such transports. To achieve this, the model incorporates an additional check, supplementing its standard assessment for patient transportation to an MTC. This supplementary check results in more multitrauma and trauma patients being sent to MTCs, expanding the number beyond those initially identified by the standard model assessment. Consequently, the overtriage percentage rises to 50%, accompanied by an improvement in the score on the 90% norm.

3. Changes 2023

Furthermore, an experiment associated with changes in 2023 in the trauma care systems is conducted. This experiment involves the exclusion of MTC status for the VUmc in Amsterdam and HagaZiekenhuis in The Hague (Amsterdam UMC, 2023; HagaZiekenhuis, 2023). Currently, these are MTCs that do not meet the established norms, making it interesting to observe the potential impacts on other MTCs due to their reclassification.

In addition to the exclusion of MTC status for these two hospitals, Network Acute Care Northwest (NAZNW) and SpoedZorgNet (SZN) merged under one new name, Network Acute Care North-Holland/Flevoland (NAZNH-FL) in 2023. This experiment also assesses the potential score on the 90% norm for this newly formed region instead of providing scores for the two individual regions. The final change examined in this experiment regarding the 2023 changes is the relocation of Lifeliner 1. Currently stationed on the VUmc rooftop, Lifeliner 1 is moved to the Amsterdam Heliport (AT5, 2023).

4a. & 4b. Helicopter transport 30 minutes and 20 minutes

Furthermore, the consideration of more frequent helicopter usage for patient transportation is being evaluated. One proposal suggests utilizing helicopters for transport if an ambulance cannot reach an MTC within 30 minutes. This is aimed at increasing the probability of transporting a patient to an MTC, striving to meet the 90% norm and reduce transportation time (Zorginstituut Nederland, 2023a). The precise consequences of this adjustment remain partially unknown, making this experiment an opportunity to gain further insights. While the model typically decides based on percentages whether the helicopter will be used for transportation, in this experiment, the choice is made based on thresholds. These experiments introduce respective thresholds of 30 minutes and 20 minutes, indicating that the helicopter is selected as the transport vehicle when the ambulance cannot reach an MTC within the specified time limit, provided both are deployed for the incident.

5.2 Results experiments

The results of the experiments are presented in Table 14, within the columns labeled “0%”, displaying the KPIs discussed in Chapter 4.6 “Key Performance Indicators” listed on the left side of the table. These KPIs are related to the trauma norms, prehospital times for both multitrauma and non-multitrauma patients and essential data about the EMSs. Please note that individual results for MTCs and ROAZ regions are not disclosed in this report due to confidentiality. To facilitate result comparison, all experiments are evaluated against the current situation, which is based on 2022 data. The model suggests that, in the current situation, 8 MTCs meet the volume norm as opposed to the actual count of 9. This discrepancy arises because one MTC barely meets the norm in reality but falls just below the norm in the model.

In the experiments “achieving the 90% norm” and “overtriage 50%”, the 90% norm score increases to 90% and 85%, respectively. In the case of achieving the 90% norm, the model ensures that every individual ROAZ region attains the 90% norm. With 50% overtriage, two regions surpass the 90% threshold. The count of MTCs meeting the minimum volume norm increases from 8 to 10 if every ROAZ region achieves the 90% norm, accommodating an additional 1100 multitrauma patients at the MTCs. With 50% overtriage, this number further increases to 11 out of 13 MTCs, with an extra 800 multitrauma patients at the MTCs. The influx of non-multitrauma patients into MTCs experiences a notable surge by increasing the overtriage percentage to 50%, tripling the number compared to the current situation. In the experiments introducing the 2023 changes, the count of MTCs meeting the volume norm also increases from 8 to 10 compared to the current situation. However, in this experiment, there are a total of 11 MTCs instead of 13. In the experiments involving the introduction of thresholds for helicopter transport, there are no changes concerning the trauma norms.

For multitrauma patients, the average transport time and prehospital time increase by approximately 3.5 minutes in the experiment where the 90% norm is met and 2.5 minutes when overtriage is increased to 50%. Consequently, fewer multitrauma patients reach hospitals within 45 and 60 minutes in these scenarios. In the experiments introducing thresholds for helicopter transport, there is a reduction in transport and prehospital time, with approximately a 1-minute reduction for a 30-minute threshold and a 1.5-minute reduction for a 20-minute threshold. For non-multitrauma patients, the average prehospital times remain relatively consistent between experiments, with one notable exception in the experiment involving 50% overtriage, where the average times increase by 7 minutes.

The model indicates that in the 50% overtriage experiment, ambulance busyness increases by approximately 13%. The other experiments show no significant changes in ambulance busyness. The busyness of the HEMS slightly increases in the experiments aimed at achieving the 90% norm and the 50% overtriage but slightly decreases in the experiments related to introducing thresholds for helicopter transport. The number of HEMS deployment cancellations decreases by 8% and 27% in the experiments where the threshold is set to 30 and 20 minutes, respectively. Additionally, the experiments with the 30 and 20-minute thresholds see a considerable increase in helicopter transport cases, rising by over 40% and 150%, respectively.

5.3 Sensitivity analysis

A sensitivity analysis is applied by adjusting the number of patients. This approach seeks to examine whether significant effects will emerge if there are more or fewer trauma patients in the Netherlands in the upcoming years. The results of this analysis are presented in Table 14, displaying the scenario with 10% fewer or more trauma patients on both the left and right sides of each experiment.

5.3.1 Adjusting the number of patients

The model suggests that variations in the number of trauma patients do not impact the 90% norm score. The trauma-multitrauma ratio remains consistent with the current ratio, indicating that multitrauma patients are likely transported to MTCs in a similar proportion.

However, a 10% decrease or increase in the number of trauma patients influences how many MTCs meet the minimum volume norm. In case of a 10% decrease, the model indicates that in all experiments, one less MTC meets the minimum volume norm, except in the scenario where overtriage is increased to 50%, where two fewer MTCs meet the norm. Conversely, for a 10% increase in patients, the number of MTCs meeting the norm remains consistent in the experiments where overtriage is increased to 50% and where the changes in 2023 were incorporated. In the experiment achieving the 90% norm, an extra MTC would meet the volume norm. In contrast, in all other experiments, two additional MTCs would meet the norm according to the model.

Notably, when examining transport times and prehospital times, no changes occurred in any experiment with variations in the number of patients. This suggests that within the model, ambulances adapt seamlessly to changes in patient volume. However, it raises the question of whether the model accounts for an excessively high number of ambulances, as it considers around 900 ambulances and it is unclear if all of them are utilized for trauma-related incidents in reality. This leads to an exploration of the possible effects when conducting experiments with a decreased number of ambulances, as elaborated in Chapter “5.3.2 Adjusting the number of ambulances”.

Regarding EMS information, the only substantial changes are observed in the busyness of ambulances and HEMS. Busyness either decreases or increases by 10%, corresponding to the decrease or increase in the patient group by 10%, which aligns logically with expectations.

Table 14: Results of the model including decrease and increase of the number of patients by 10%

	Current (2022)			Achieving 90% norm			Overtriage 50%			Changes 2023			Helicopter transport 30 min			Helicopter transport 20 min			
Change in number of patients	**-10%**	**0%**	**+ 10%**	**-10%**	**0%**	**+ 10%**	**-10%**	**0%**	**+ 10%**	**-10%**	**0%**	**+ 10%**	**-10%**	**0%**	**+ 10%**	**-10%**	**0%**	**+ 10%**	
Nationwide score 90% norm	69%	69%	69%	90%	90%	90%	85%	85%	85%	69%	69%	69%	69%	69%	69%	70%	70%	70%	**Trauma norms**
Number of ROAZ regions meeting 90% norm	0 of 11	0 of 11	0 of 11	11 of 11	11 of 11	11 of 11	2 of 11	2 of 11	2 of 11	0 of 10	0 of 10	0 of 10	0 of 11	0 of 11	0 of 11	0 of 11	0 of 11	0 of 11	
Number of MTCs meeting volume norm	7 of 13	8 of 13	10 of 13	9 of 13	10 of 13	11 of 13	9 of 13	11 of 13	11 of 13	9 of 11	10 of 11	10 of 11	7 of 13	8 of 13	10 of 13	7 of 13	8 of 13	10 of 13	
Number of multitrauma patients at MTCs	3305	3669	4027	4292	4760	5226	4036	4477	4920	3277	3634	3990	3294	3656	4013	3327	3693	4054	
Number of non-multitauma patients at MTCs	8996	9982	10993	9000	9979	10989	27713	30724	33834	8192	9090	10013	8983	9966	10976	9084	10074	11094	
Average transportation time multitrauma patients in minutes	19:37	19:37	19:36	22:57	22:55	22:55	22:01	21:59	21:59	19:46	19:45	19:47	18:45	18:44	18:44	18:08	18:07	18:06	**Times multitrauma patients**
Average prehospital time multitrauma patients in minutes	54:25	54:21	54:18	57:43	57:38	57:40	56:51	56:49	56:45	54:30	54:32	54:32	53:35	53:28	53:31	53:06	53:04	53:02	
Fraction of multitrauma patients with prehospital time < 45 minutes	35%	35%	35%	28%	28%	28%	30%	30%	30%	35%	35%	34%	36%	36%	36%	37%	38%	38%	
Fraction of multitrauma patients with prehospital time < 60 minutes	65%	66%	66%	59%	59%	59%	60%	61%	61%	65%	65%	66%	67%	68%	68%	68%	69%	69%	
Average transportation time non-multitrauma patients in minutes	13:28	13:28	13:28	13:28	13:28	13:27	20:24	20:23	20:23	13:28	13:28	13:27	13:28	13:28	13:27	13:26	13:26	13:26	**Times non-multitrauma patients**
Average prehospital time non-multitrauma patients in minutes	47:43	47:43	47:42	47:43	47:43	47:42	54:39	54:38	54:38	47:43	47:43	47:43	47:43	47:43	47:42	47:41	47:41	47:41	
Fraction of non-multitrauma patients with prehospital time < 45 minutes	46%	46%	46%	46%	46%	46%	34%	34%	34%	46%	46%	46%	46%	46%	46%	46%	46%	46%	
Fraction of non-multitrauma patients with prehospital time < 60 minutes	81%	81%	81%	81%	81%	81%	66%	66%	66%	81%	81%	81%	81%	81%	81%	81%	81%	81%	
Busyness ambulance (only trauma-related incidents)	0.56%	0.62%	0.68%	0.56%	0.62%	0.68%	0.63%	0.70%	0.77%	0.56%	0.62%	0.68%	0.56%	0.62%	0.68%	0.55%	0.61%	0.68%	**EMS information**
Busyness HEMS (only trauma-related incidents)	3.43%	3.80%	4.17%	3.52%	3.89%	4.29%	3.64%	4.03%	4.42%	3.43%	3.79%	4.18%	3.35%	3.71%	4.08%	3.28%	3.63%	4.01%	
Fraction HEMS cancelled based on time	20.96%	20.75%	20.84%	20.88%	20.97%	20.82%	20.94%	20.72%	20.78%	21.05%	21.28%	21.54%	18.85%	19.10%	18.55%	15.33%	15.20%	14.92%	
Fraction helicopter used for transport when present	17.26%	17.28%	17.35%	17.43%	17.22%	17.04%	17.22%	17.38%	17.35%	17.62%	17.49%	17.50%	24.46%	24.47%	24.44%	43.25%	43.26%	42.94%	

5.3.2 Adjusting the number of ambulances

The initial stage in conducting a sensitivity analysis on adjusting ambulance numbers involves identifying significant reductions. To determine these, tests were conducted by gradually decreasing the ambulance count by 5% until noticeable differences emerged. While reducing ambulances does not impact patient transport time, it notably affects ambulance response times. The analysis focuses on pinpointing the point at which response times deviate by more than 5%, comparing the current 2022 scenario with and without the reduced number of ambulances. This change occurs at a 30% reduction in ambulance numbers, leading to the decision to run all experiments with 30% fewer ambulances. Additionally, a scenario involving double the reduction in the number of ambulances is introduced, resulting in a 60% decrease.

In this sensitivity analysis, the ambulance count per station is multiplied by 0.7 and 0.4 and then rounded to the nearest integer to achieve a 30% and 60% reduction, respectively. For instance, a station initially having 6 ambulances would have 4 with a 30% reduction (6 * 0.7 = 4.2 -> 4) and 2 with a 60% reduction (6 * 0.4 = 2.4 -> 2). However, to prevent reducing eight stations to zero ambulances in the case of a 60% decrease, as they initially had one ambulance, they are set to one, ensuring at least one ambulance per station is maintained. Including these eight ambulances has minimal impact on the results. While this method does not precisely achieve a 30% or 60% reduction, it closely approximates these reductions. Otherwise, a challenging decision would be necessary regarding which stations would lose ambulances in the model, lacking a clear basis for such choices.

The outcomes of this analysis are presented in Table 15. In the table, results for scenarios with the original number of ambulances, a 30% decrease and a 60% decrease can be observed from left to right across all experiments. Notably, this analysis examines changes in response time rather than patient transportation times. Regarding the trauma norms scores, the model exhibits no significant changes when the number of ambulances decreases in the model. Although there are rare occurrences where a different hospital is chosen for a patient compared to the original experiments, such instances have a negligible impact on the norms.

For response time, a consistent pattern emerges across all experiments. The response time for multitrauma patients, on average, increases by 1 minute for a 30% decrease in ambulances and approximately 2 minutes for a 60% decrease. A similar pattern is observed for non-multitrauma patients, with a 1-minute increase for a 30% decrease and slightly more than a 2-minute increase for a 60% decrease in ambulances. The total prehospital time experiences the same increase in minutes as the response time, resulting in a slight decrease in the percentage of patients reaching the hospital within 45 and 60 minutes within the model.

Consistent patterns also emerge in the busyness of EMSs across all experiments. With a 30% decrease in ambulances, the busyness of the ambulances increases by almost 50% and with a 60% decrease, busyness increases by 140% in the model compared to the experiments with the original number of ambulances. For HEMS, there is a slight increase in busyness as the number of ambulances decreases. The fraction of canceled HEMS deployments reduces as ambulance numbers decrease, with cancellations dropping by 4% to 9% for a 30% decrease and by 13% to 16% for a 60% decrease in ambulances.

Table 15: Results reducing the number of ambulances in the model

	Current (2022)			Achieving 90% norm			Overtriage 50%			Changes 2023			Helicopter transport 30 min			Helicopter transport 20 min			
Change in number of ambulances	**0%**	**-30%**	**-60%**	**0%**	**-30%**	**-60%**	**0%**	**-30%**	**-60%**	**0%**	**-30%**	**-60%**	**0%**	**-30%**	**-60%**	**0%**	**-30%**	**-60%**	
Nationwide score 90% norm	69%	69%	70%	90%	90%	90%	85%	85%	85%	69%	69%	69%	69%	69%	69%	70%	70%	70%	**Trauma norms**
Number of ROAZ regions meeting 90% norm	0 of 11	0 of 11	0 of 11	11 of 11	11 of 11	11 of 11	2 of 11	2 of 11	2 of 11	0 of 10	0 of 10	0 of 10	0 of 11	0 of 11	0 of 11	0 of 11	0 of 11	0 of 11	
Number of MTCs meeting volume norm	8 of 13	8 of 13	8 of 13	10 of 13	10 of 13	10 of 13	11 of 13	11 of 13	11 of 13	10 of 11	10 of 11	10 of 11	8 of 13	8 of 13	8 of 13	8 of 13	8 of 13	8 of 13	
Number of multitrauma patients at MTCs	3669	3668	3670	4760	4760	4761	4477	4478	4479	3634	3639	3637	3656	3656	3656	3693	3693	3701	
Number of non-multitauma patients at MTCs	9982	9979	9982	9979	9981	9981	30724	30725	30725	9090	9091	9095	9966	9966	9967	10074	10074	10071	
Average transportation time multitrauma patients in minutes	10:22	11:11	12:13	10:22	11:10	12:15	10:23	11:11	12:15	10:22	11:11	12:13	10:21	11:12	12:15	10:22	11:10	12:14	**Times multitrauma patients**
Average prehospital time multitrauma patients in minutes	54:21	55:10	56:09	57:38	58:31	59:28	56:49	57:36	58:39	54:32	55:18	56:20	53:28	54:22	55:25	53:04	53:49	54:50	
Fraction of multitrauma patients with prehospital time < 45 minutes	35%	34%	32%	28%	27%	26%	30%	29%	27%	35%	33%	31%	36%	35%	33%	38%	36%	34%	
Fraction of multitrauma patients with prehospital time < 60 minutes	66%	64%	62%	59%	57%	55%	61%	59%	57%	65%	64%	62%	68%	66%	64%	69%	67%	65%	
Average transportation time non-multitrauma patients in minutes	12:38	13:38	14:55	12:38	13:38	14:56	12:39	13:39	14:58	12:38	13:37	14:55	12:38	13:37	14:56	12:38	13:38	14:55	**Times non-multitrauma patients**
Average prehospital time non-multitrauma patients in minutes	47:43	48:42	50:00	47:43	48:42	50:01	54:38	55:38	56:58	47:43	48:42	50:00	47:43	48:42	50:00	47:41	48:41	49:58	
Fraction of non-multitrauma patients with prehospital time < 45 minutes	46%	44%	41%	46%	44%	41%	34%	32%	30%	46%	44%	41%	46%	44%	41%	46%	44%	41%	
Fraction of non-multitrauma patients with prehospital time < 60 minutes	81%	79%	76%	81%	79%	76%	66%	64%	62%	81%	79%	76%	81%	79%	76%	81%	79%	76%	
Busyness ambulance (only trauma-related incidents)	0.62%	0.91%	1.49%	0.62%	0.92%	1.50%	0.70%	1.03%	1.67%	0.62%	0.91%	1.49%	0.62%	0.91%	1.48%	0.61%	0.91%	1.48%	**EMS information**
Busyness HEMS (only trauma-related incidents)	3.80%	3.87%	3.98%	3.89%	3.99%	4.07%	4.03%	4.11%	4.21%	3.79%	3.88%	3.97%	3.71%	3.79%	3.87%	3.63%	3.69%	3.76%	
Fraction HEMS cancelled based on time	20.75%	19.44%	17.71%	20.97%	19.21%	17.67%	20.72%	19.44%	17.71%	21.28%	19.74%	18.20%	19.10%	17.37%	16.12%	15.20%	14.53%	13.22%	
Fraction helicopter used for transport when present	17.28%	17.05%	16.70%	17.22%	16.91%	16.75%	17.38%	17.37%	16.85%	17.49%	17.62%	17.01%	24.47%	24.26%	24.03%	43.26%	42.91%	42.50%	

5.4 Chapter summary

This chapter conducts various experiments exploring potential future scenarios and their impacts. Experiments include achieving the 90% norm, increasing overtriage to 50%, implementing 2023 changes in trauma care and introducing helicopter transport thresholds. Results, compared to 2022 data, show that achieving the 90% norm yields a nationwide score of 90% on the norm and overtriage at 50% results in 85%. All ROAZ regions meeting the 90% norm increase the number of MTCs meeting the minimum volume norm to 10 and it rises to 11 with the experiment of 50% overtriage. Introducing 2023 changes sees 10 MTCs meeting the volume norm with a total of 11 MTCs.

For multitrauma patients, meeting the 90% norm and 50% overtriage increases transportation and total prehospital times by 3.5 and 2.5 minutes, respectively. Helicopter transport thresholds reduce times by approximately 1 and 1.5 minutes for 30-minute and 20-minute thresholds. Non-multitrauma patients' transportation and total prehospital times remain consistent, except in the 50% overtriage percentage, where they show a notable increase of 7 minutes on average.

In the 50% overtriage experiment, ambulance busyness rises by around 13%, while HEMS busyness slightly varies across experiments, increasing in those targeting the 90% norm and 50% overtriage but decreasing in those introducing helicopter transport thresholds. Helicopter thresholds of 30 and 20 minutes reduce HEMS cancellations by 8% and 27%, with the number of helicopter transports increasing by 40% and 150%, respectively.

Trauma patient number variations do not affect the 90% norm score. A 10% change in patient numbers influences the number of MTCs meeting the volume norm. Ambulance number variations have little impact on trauma norm scores. Response and total prehospital times experience a 1-minute increase for a 30% decrease in ambulances and approximately a 2-minute increase for a 60% decrease. A consistent pattern in busyness is observed, with a 30% ambulance decrease causing nearly a 50% increase and a 60% decrease leading to a 140% increase. Reductions in ambulance numbers decrease HEMS deployment cancellations in the model, ranging from 4% to 9% for a 30% decrease and 13% to 16% for a 60% decrease.

6. Conclusion

This conclusion begins by examining the research findings. It then moves on to consider key discussion points and concludes by presenting potential recommendations for future research.

6.1 Conclusion

This research addressed the core problem: “*What are the consequences of meeting trauma norms for acute care organizations in the Netherlands on patient transportation time, emergency medical service busyness and hospital capacity?”*

Initially, the research examines the trauma norms and identifies contributing factors to their inconsistent adherence. Subsequently, the research explores the structure of the Dutch trauma system and evaluates how the MTCs and ROAZ regions currently score on the norms. A literature review is conducted to identify potential elements for constructing a model that can be used to experiment with different scenarios to observe their effects on norm compliance, patient transportation times and emergency medical service capacity. The model’s validation incorporated 2022 data and consisted of experiments aimed at achieving the 90% norm, increasing overtriage to 50%, accounting for the current 2023 changes and investigating helicopter utilization for patient transport when the ambulance-to-MTC transport time exceeded either 30 or 20 minutes, provided both vehicles were deployed for the incident. Sensitivity analyses are also conducted for these experiments, involving a 10% reduction or increase in the number of trauma patients and a 30% or 60% reduction in the number of ambulances compared to the original model. Key conclusions from each experiment are outlined below.

Achieving 90% norm

The experiment results regarding achieving the 90% norm reveal that, according to the model, even if all ROAZ regions meet the 90% norm, some MTCs still fail to meet the minimum volume norm. Specifically, the model indicates that three MTCs would not meet the volume norm and even with a 10% increase in trauma patients, two MTCs would still fall short of the total 13 MTCs. Achieving the 90% norm in the future could lead to an average increase of approximately 3.5 minutes in transportation time and prehospital time for multitrauma patients. Notably, EMS busyness would remain constant, as the prolonged prehospital times primarily affect the additional multitrauma patients directed to MTCs. With an extra 1100 multitrauma patients annually, this averages about three multitrauma patients daily, which is relatively modest.

Overtriage 50%

Increasing the overtriage percentage to 50% results in a notable influx of trauma patients at the MTCs, leading to extended transportation and prehospital times and not guaranteeing the achievement of the 90% norm. The number of trauma patients at the MTCs triples compared to the current situation. The average transport and prehospital time for multitrauma patients increase by approximately 2.5 minutes. Notably, the average transport time for non-multitrauma patients experiences a substantial 7-minute increase, reflecting a rise of over 50%. Consequently, ambulance and HEMS busyness rises by around 13% and 6%, respectively. Although the model suggests that increasing the overtriage percentage to 50% elevates the 90% norm score to around 85%, regional analysis reveals only two ROAZ regions surpassing the 90% norm under these conditions, implying that many regions still fall short. A 50% overtriage leads to 11 out of 13 MTCs meeting the minimum volume norm.

Changes 2023

The implementation of changes in 2023 does not improve the 90% norm score. However, these changes, including the exclusion of VUmc and Hagaziekenhuis from MTC status, positively affect the number of MTCs meeting the minimum volume norm. Despite these changes, the model indicates that one of the 11 remaining MTCs still does not meet this norm, even with a 10% increase in trauma patients. Notably, these changes do not influence average prehospital times and EMS busyness.

Helicopter transport 30 minutes and 20 minutes

Introducing thresholds for helicopter transport has no impact on either trauma norm. Average transport times and total prehospital times for multitrauma patients decrease by approximately 1 and 1.5 minutes, respectively, with 30-minute and 20-minute thresholds. There are no changes in times for non-multitrauma patients or ambulance busyness. According to the model, introducing these thresholds results in a decrease in the busyness of HEMS. This is because, in the model's perspective, HEMS is considered busy even when it travels to the hospital without a patient to await the ambulance with the patient and the HEMS physician. The model suggests that, on average, the helicopter becomes available more quickly to other patients if it transports the patient itself instead of the ambulance. Additionally, the model predicts a decrease in the number of HEMS cancellations, as the helicopter is more frequently chosen as the means of transport, completing its journey more often within the model. With a 30-minute threshold, the number of helicopter transports would increase by about 40% and with a 20-minute threshold, the increase would be more than 150%.

Sensitivity analysis – adjusting the number of ambulances

Reducing the number of ambulances in the model results in minimal changes concerning trauma norms. The model demonstrates changes in patient response and total prehospital time, EMS busyness and HEMS cancellations. Consistent patterns emerge across all experiments. On average, a 30% reduction in ambulances within the model leads to a 1-minute increase in response and total prehospital time for all patients. This increment rises to approximately 2 minutes with a 60% decrease in ambulances, as the limited number necessitates longer travel distances. Ambulance busyness considerably rises, nearly 50% with a 30% reduction and 140% with a 60% reduction, since the same workload must be managed with fewer vehicles. The extended response time adds to the increased busyness of the ambulances when compared to experiments conducted with the original number of ambulances. Additionally, because ambulances take longer, on average, to reach the incident and consequently complete on-scene treatment later, HEMS cancellations due to time constraints become less frequent. Cancellations decreased by 4% to 9% for a 30% reduction and by 13% to 16% with a 60% reduction in ambulances, leading to more frequent completion of HEMS deployments and a slight increase in the HEMS busyness.

6.2 Discussion

The constructed simulation model includes various elements, incorporating three distinct vehicles with their unique characteristics, gradations in incident severity and distinctions between MTCs and regional hospitals in the Netherlands. To calculate different prehospital time intervals, the model considers factors such as the vehicle type, urgency of deployment, incident severity, transportation vehicle choice, selected hospital and potential deviations arising from factors like traffic and weather conditions. The model relies on probabilities derived from available data to emulate decisions typically handled by humans, like selecting the appropriate vehicles for an incident, their origin and identifying the nearest suitable hospital for the patients.

Despite its attempts to mirror human decision-making using probabilities, the model cannot perfectly replace the nuanced nature of human decisions. For instance, the model determines whether a patient is a multitrauma patient and needs transport to an MTC immediately upon incident generation. In reality, such determinations about whether a patient is a multitrauma case typically occur later, within the hospital setting. In certain real-world scenarios, medical considerations may lead to choosing a slightly more distant hospital, differing from the model's tendency to transport patients to the nearest MTC or hospital based on predefined criteria.

In the experiment where the overtriage percentage is increased, all patients in the model have an increased chance of being directed to an MTC. If, instead of randomly directing additional patients to MTCs, specific patient groups with a higher probability of being multitrauma cases are prioritized during increased overtriage, the model outcomes may slightly vary. A limitation lies in the model's use of a somewhat 'blind' overtriage approach, neglecting patient characteristics. However, it is acknowledged that making accurate on-the-spot assessments is challenging, especially for patients with moderate injuries, where the likelihood of being a multitrauma patient is notable. It is observed that the patient group with an ISS between 9-15, indicating moderate severity, constitutes a substantial portion, comprising 43% of the total patient group. This percentage is just a bit smaller than the overtriage rate applied in the increased overtriage experiment, ensuring that the model's overtriage approach is not entirely blind (Kramer & Poeze, 2023).

In terms of helicopter transportation time, conversations with an MMT medical coordinator and physician indicate that the process of loading a patient into the helicopter and subsequently transporting them from the helicopter landing point to the emergency department takes more time compared to when performed by an ambulance. While the model factors in post-transport time, covering the duration from landing to reaching the incident, it does not incorporate additional loading time and the time between landing and reaching the emergency room department due to the absence of specific data on these aspects. Consequently, the model may present helicopter transportation time as more advantageous than it is in reality.

Several assumptions and simplifications are made in this research, potentially influencing the results. The model treats level II and III hospitals without differentiation, disregarding the actual differences in the types of patients they receive. While this might lead to underestimating multitrauma patients at some level II hospitals and overestimating them at some level III hospitals, its overall impact on the model's results is limited. Additionally, an assumption is made about hospitals having infinite capacity, enabling estimations of patient distributions. However, real-world decisions might involve patient transfers to other hospitals due to capacity constraints. It is important to note that an MTC must always have a bed available for admitting a multitrauma patient.

The model assumes all MMT dispatches are primary, disregarding secondary dispatches based on first responder medical assessments. MMT deployments are canceled within the model when an ambulance reaches the incident, the patient is treated and the ambulance is ready for transport when the MMT has not yet arrived. The model does not consider cancellations based on medical considerations. While this time-based approach underestimates the number of MMT deployments, its impact on the model results is minimal due to the relatively low daily MMT dispatches. The quantity of completed MMT dispatches within the model closely mirrors real-world data. Additionally, the study includes two German helicopters, but all incidents in the model are situated in the Netherlands. The exclusion of German patients near the border results in a somewhat exaggerated deployment estimation for the German helicopters, as they are utilized for incidents in Germany as well.

Lastly, the question was raised about whether the model accurately represents the actual ambulance count, as it considers around 900 ambulances and it is unclear if all of them are deployed for trauma-related incidents in reality. To address this, a sensitivity analysis was conducted with a 30% and 60% reduction in the number of ambulances. The analysis revealed that decreasing the number of ambulances in the model has no impact on the trauma norms and, on average, results in a slight increase in response and total prehospital times.

6.3 Future research

To enhance the validity of the results, further research could be conducted. While the model predominantly utilized national data, providing accurate results at the national level, data availability at the local or regional level was sometimes limited during this research. Having more data at this level would enable more precise results, particularly concerning prehospital time intervals at ROAZ or RAV levels. Several assumptions were made about incident locations in the model to ensure a representative distribution, but having more accurate data on incident locations and patient destinations would further enhance the model's realism.

In the experiment involving an increase in the overtriage percentage, all patients in the model experienced an increased chance of being directed to an MTC. However, in reality, additional patients directed to MTCs would not be selected randomly. Instead, those for whom there is uncertainty about whether they are multitrauma patients would be prioritized for MTC transport. Future research could uncover which patient groups frequently seem non-multitrauma at first glance but are later identified as multitrauma patients upon reaching the hospital. This may pertain to patients involved in a specific type of incident, those with particular injuries and/or individuals within a certain age group. Improved insights in this regard could facilitate the direct transportation of more multitrauma patients to MTCs.

The model incorporated thresholds for helicopter utilization as a transport vehicle. Presently, helicopter transport of patients is limited, primarily attributed to constraints in the helicopter's working space. Further research could explore adaptations to enhance the helicopter's suitability for patient transport. Another frequently raised question relates to the inclusion of additional MMTs. Initially, the plan was to explore the impact of adding helicopters and ground vehicles at various locations in the country. However, challenges arose, as an increased number of helicopters and ground vehicles in the country may lead to more frequent use, even for cases that currently do not involve MMTs due to their limited availability. Investigating how many additional MMT deployments would occur with the addition of helicopter or ground vehicles at specific locations is essential for making relevant statements about the impact of expanding MMTs.

Finally, performance indicators related to the quality of care and costs were beyond the scope of this research. To create a more comprehensive picture, additional research could explore the impact of certain effects on these two aspects. For instance, increasing helicopter usage might incur additional costs. Some experiments within the study saw an increase in response, transportation and/or total prehospital time, which could have implications for patient health. Additionally, in the model, HEMS cancellations were solely based on time, not considering medical factors. Integrating the medical aspect could bring the number of cancellations into closer alignment with reality and consider secondary dispatches.

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Appendix A: Probability distributions

In the model, various prehospital activities are governed by probability distributions. Identifying the most appropriate probability distributions for these activities involves an examination of the available existing data. However, due to the absence of data for individual cases, the analysis predominantly relies on available statistics, including means, standard deviations and medians. This appendix focuses on four key prehospital activities: response time, travel time, treatment time and handover time.

Response time

Response time consists of several components, including incident report processing by the control room operator, EMS deployment time, travel time to the incident scene and, for helicopters, the time taken to reach the scene from the landing point. In the model, the processing time of the control room operator, EMS deployment and helicopter post-transport is treated collectively as one process. Data from Ambulancezorg Nederland (2023) revealed that the median response time is lower than the average response time for both A1 and A2 deployments. Specifically, the median response time for A1 deployments is 9:42 minutes, whereas the mean is 10:12 minutes. For A2 deployments, the median is 14:31 minutes and the mean is 15:56 minutes. Regarding the post-transport time, while there are considerable variations around the average, there are relatively few instances of significantly long post-transport times (Zwakhals et al., 2008). Considering these factors, along with the constraint that response time cannot be negative, the gamma distribution is considered a reasonable choice for modeling this process. As shown in Figure 6, the distribution illustrates the response time for A1 ambulance deployments. The horizontal axis displays response time in seconds, while the vertical axis represents the probability associated with specific response times.

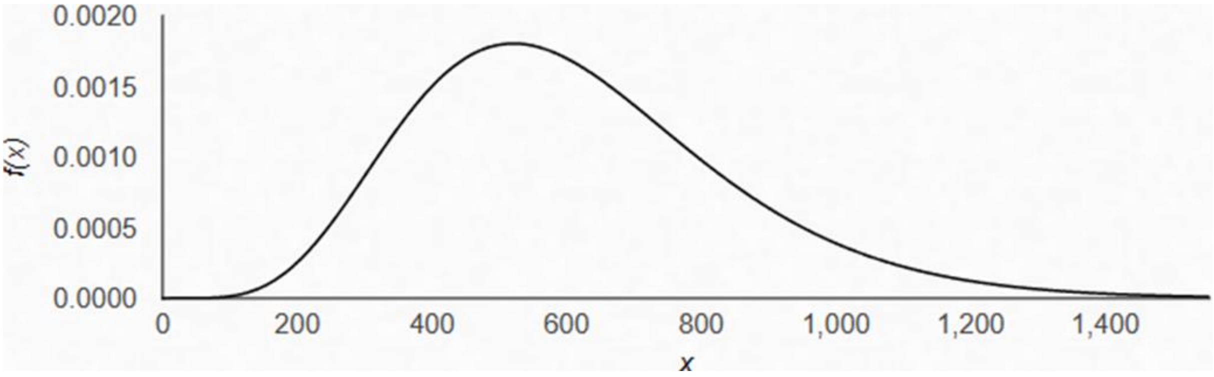

Figure 6: Distribution response time A1 deployments ($\alpha = 6.74$, $\beta = 90.80$)

Travel time

Travel time to the incident, whether by ground-based vehicles or helicopter, is approximated using average times between different postal codes. While slight variations may occur due to factors like traffic and weather conditions, these differences are likely to be minor. Consequently, a normal distribution with a standard deviation of 5% of the mean travel time is deemed suitable for modeling both driving and flight durations. Figure 7 depicts an example illustrating the distribution of the travel time between two postal codes, assumed to be 10 minutes for this example, resulting in a standard deviation of 5% * 10 minutes = 0.5 minutes.

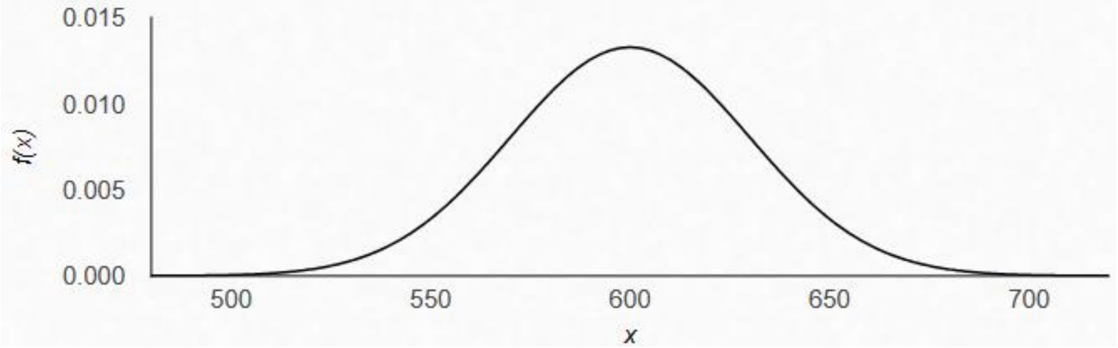

Figure 7: Example distribution travel time: 10 minutes (μ = 600, σ = 30)

Treatment time

Despite the absence of data on individual patient treatment time, it is worth noting that the median treatment time is lower than the mean treatment time according to data of the LTR. This observation, coupled with the fact that treatment time cannot be negative, suggests that the gamma distribution could be a suitable choice for modeling treatment time. The distribution for patients with an ISS>24 is displayed in Figure 8.

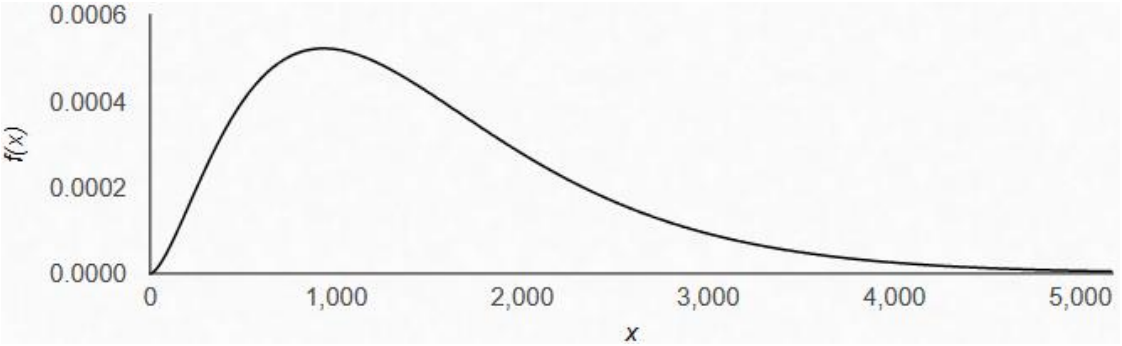

Figure 8: Distribution treatment time ISS>24 (α = 2.65, β = 564.12)

Handover time

Information on handover times from EMS vehicles to hospitals is limited, with only average handover times available for different RAV regions. Most RAV regions report times below the national average, with a few outliers displaying higher times. Notably, the gamma distribution is often suitable for processes involving task completion and the handover time data likely exhibits a right-skewed pattern, similar to response and treatment times. Therefore, the gamma distribution is considered a reasonable choice for modeling handover time. The distribution for the handover time for an A1 ambulance deployed is presented in Figure 9.

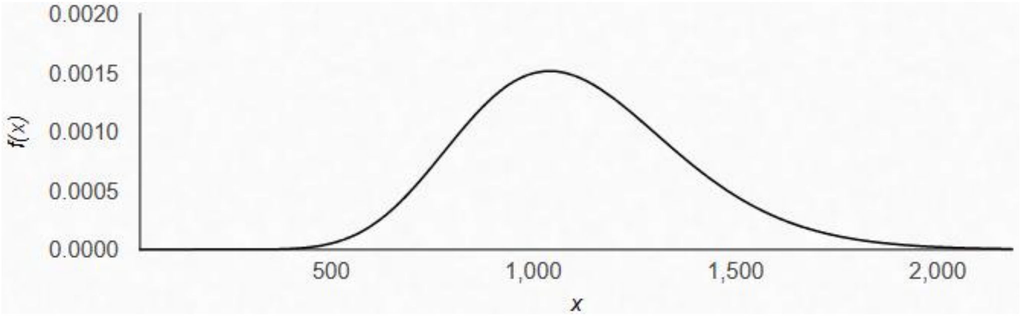

Figure 9: Distribution handover time A1 deployments (α = 16.85, β = 65.68)

Appendix B: Flowcharts of the simulation model logic

In this appendix, a comprehensive breakdown of the model's sub-processes is provided. Multiple flow charts are designated to visually illustrate the embedded logic within the simulation model.

Sub-process: Incident

In Figure 10, the process of incident generation within the simulation model is presented.

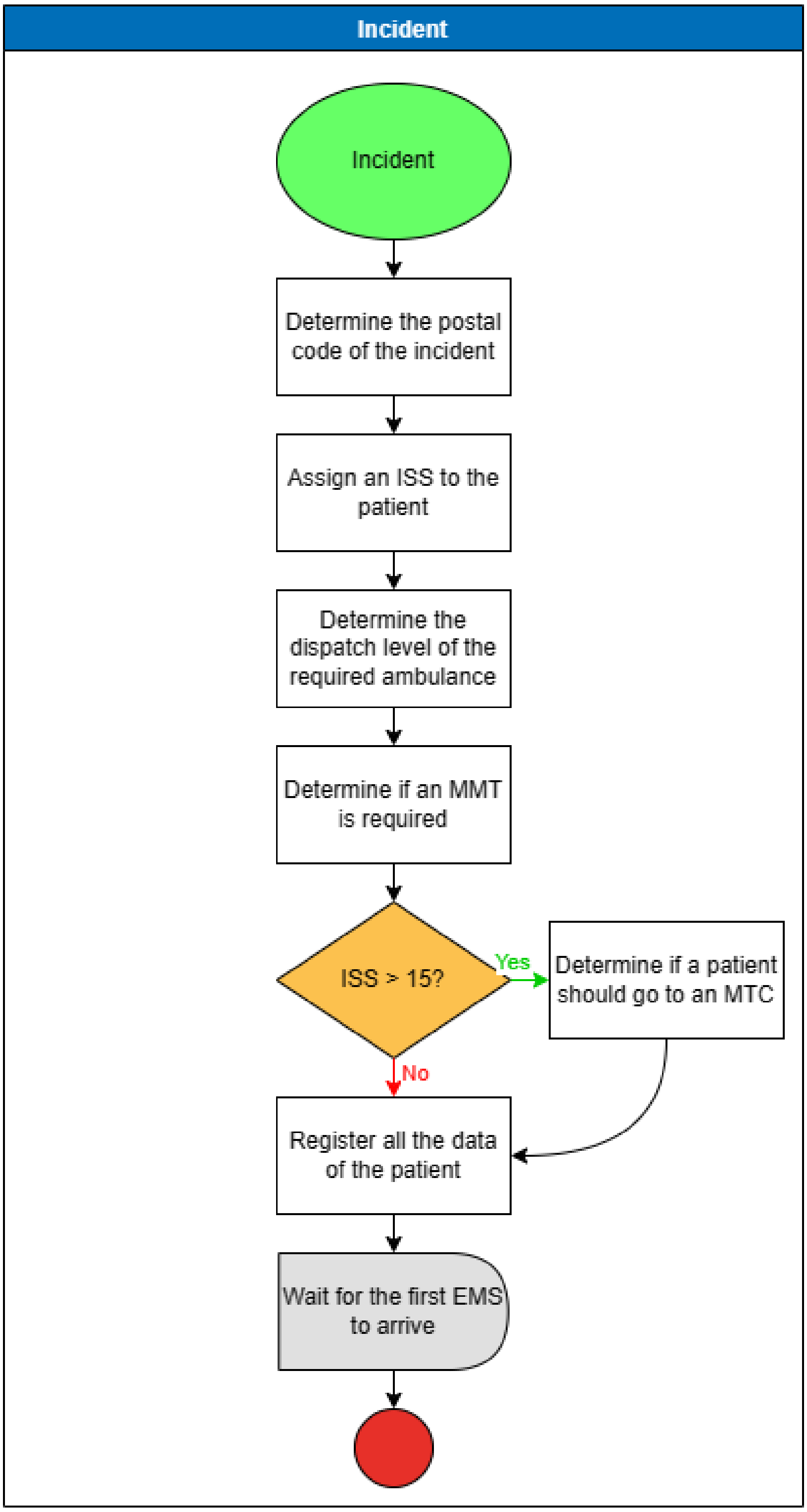

Figure 10: Flowchart of the process of generating an incident

The model generates incidents using the Poisson distribution, considering the time of the day. More incidents occur during the afternoon and evening compared to the morning and night (Kramer & Leenen, 2022). Upon incident generation, the model initially determines the incident's postal code. Each postal code carries a specific probability of experiencing an incident, based on population numbers of various postal codes and the count of trauma patients in different ROAZ regions. Consequently, incidents are more likely in densely populated areas and regions with a higher number of trauma patients.

Once the incident's location is established, the model assigns an ISS to the patient, categorizing it as ISS<15, 15<ISS≤24 or ISS>24. Certain regions in the country have a higher likelihood of a higher ISS. Although the ISS is typically determined in the hospital, the model assigns an ISS at the incident generation stage. Based on both the incident's location and the ISS, the model establishes the dispatch level of the required ambulance and determines if an MMT is necessary.

For ISS>15, the model mandates an ambulance dispatch level of A1. In cases with ISS<15, the dispatch level could be either A1 or A2. Patients with a higher ISS are also more likely to necessitate an MMT dispatch. Additionally, for patients with ISS>15, the model makes an extra decision on whether the patient should be directed to an MTC. While this decision is typically made on-scene by medical professionals, the model predetermines it during incident generation based on probabilities, striving to align with the distribution of multitrauma patients seen in reality. The incident's region influences this decision, as some regions prioritize sending patients to MTCs, especially those with higher ISS values. All patient data is stored and the patient awaits the arrival of the first EMS.

Sub-process: Dispatch

Following incident generation, the subsequent step, illustrated in Figure 11, involves dispatching the required EMS(s).

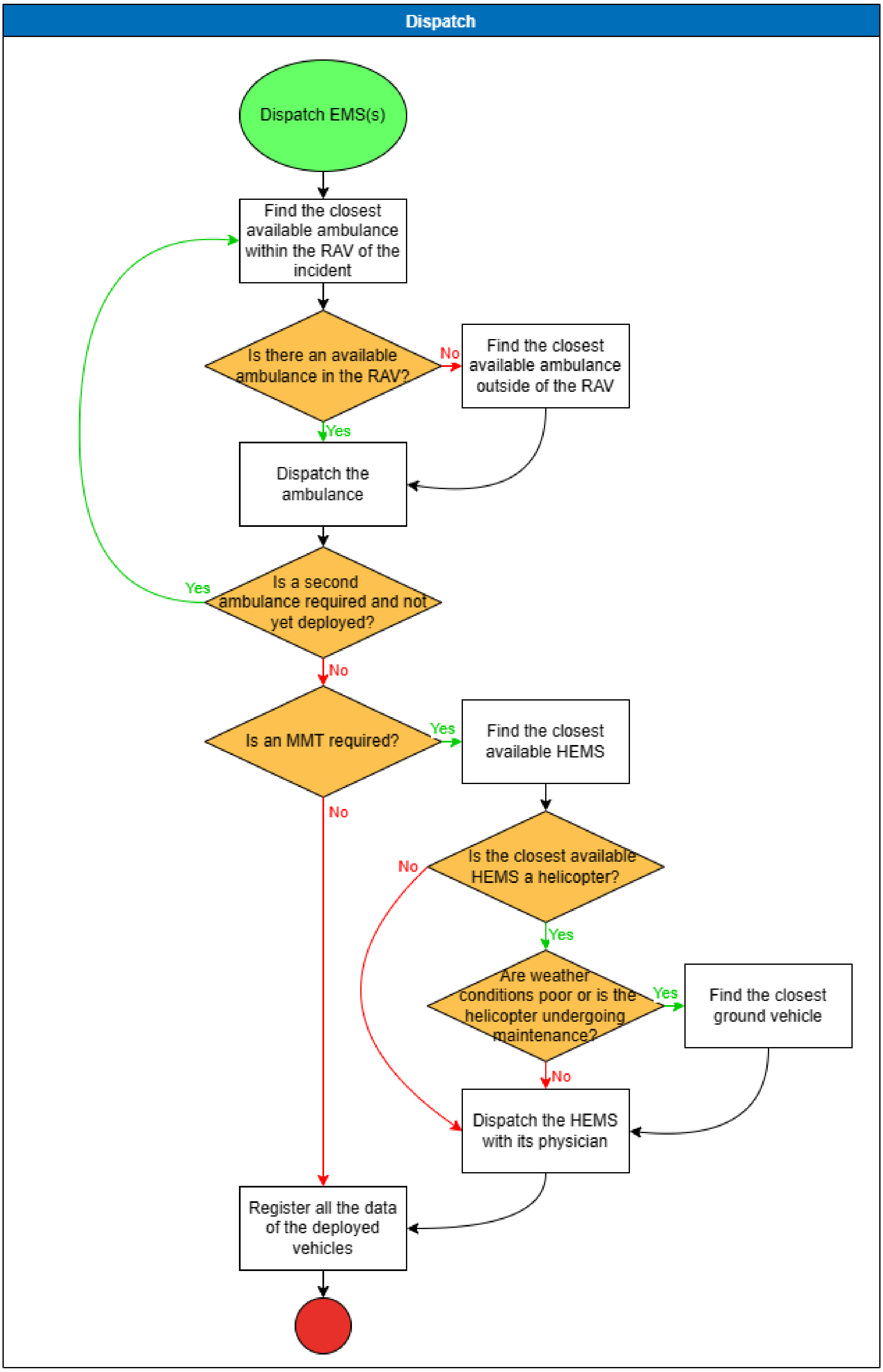

Figure 11: Flowchart of the process of dispatching EMS(s)

During incident generation, decisions regarding the dispatch level of the ambulance and the potential need for an MMT are pre-determined. The model initiates a search for the closest available ambulance within the RAV of the incident. Ambulance availability is verified by checking if the vehicle is not already engaged in another incident and a busy probability is factored in to address non-trauma-related incidents not considered in the model. If an available ambulance is located within the RAV, it is dispatched to the patient. In the absence of an available ambulance within the RAV, the model then seeks the nearest available ambulance outside the RAV. The decision to primarily search within the RAV is made to maximize ambulance occupancy within all RAVs. While a single ambulance is typically adequate, there are situations, such as real-life resuscitation cases, where a second ambulance may be deemed necessary. In such cases, the model searches for an additional nearest available ambulance.

For incidents requiring an MMT, the model identifies available HEMS teams capable of the fastest response. Here, a busy probability is also factored in to accommodate non-trauma-related incidents. If the nearest available vehicle happens to be a helicopter, the model assesses a probability considering constraints like weather conditions or helicopter maintenance that might hinder deployment. If the helicopter can be deployed, it is dispatched to the incident alongside the HEMS physician stationed at that location. If helicopter deployment is not possible, the model searches for the nearest ground vehicle. The team can only be deployed when the HEMS physician is present, ensuring that the helicopter and the ground vehicle stationed at the same location cannot be dispatched simultaneously. After all required vehicles have been deployed, the data of these vehicles is registered.

Sub-process: Treatment

The sub-process illustrating the treatment of the patient at the scene is depicted in Figure 12.

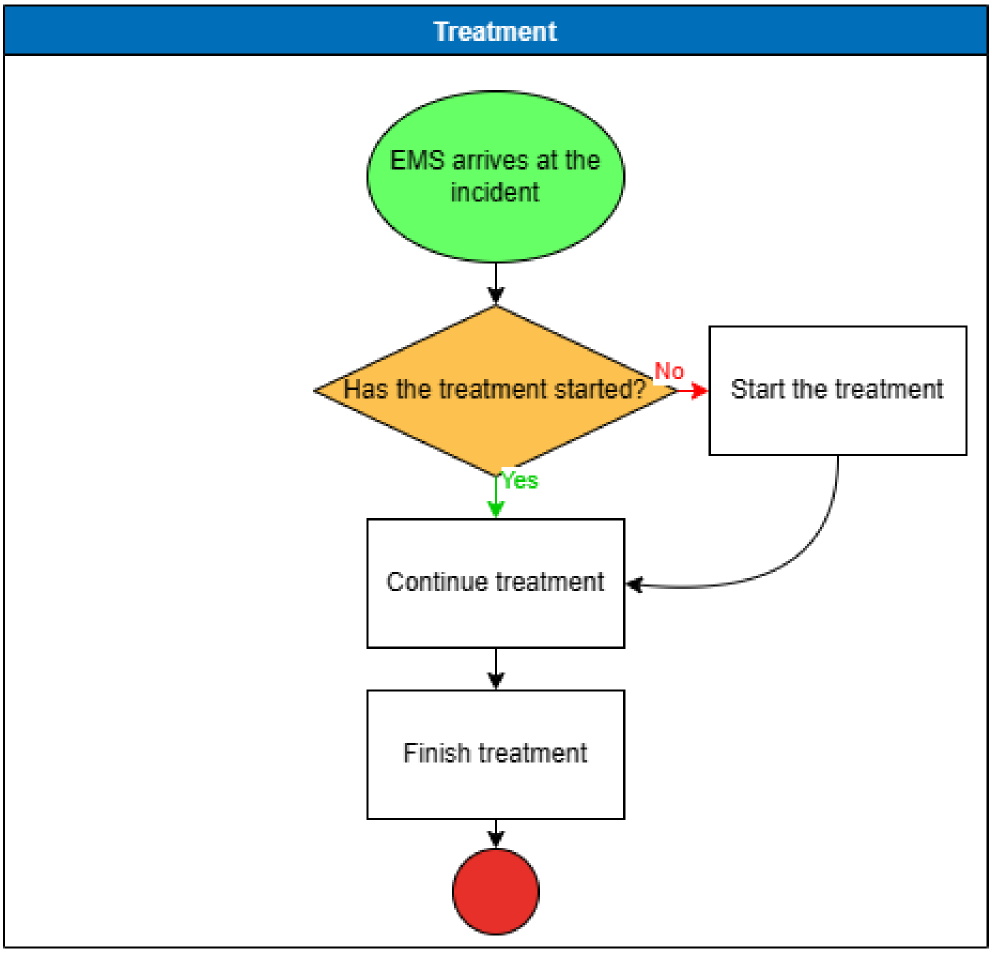

Figure 12: Flowchart of the process of carrying out the treatment

Upon the arrival of the first EMS at the incident, the patient's treatment commences. The duration of treatment correlates with the patient's ISS; a higher ISS correlates with a greater probability of a prolonged treatment period. The established patient treatment time remains constant, unaffected by the arrival of additional vehicles at the incident. Once the treatment concludes, the patient is prepared for transport.

Sub-process: Mode of transport

The sub-process outlining the selection of the transportation mode for the patient is detailed in Figure 13.

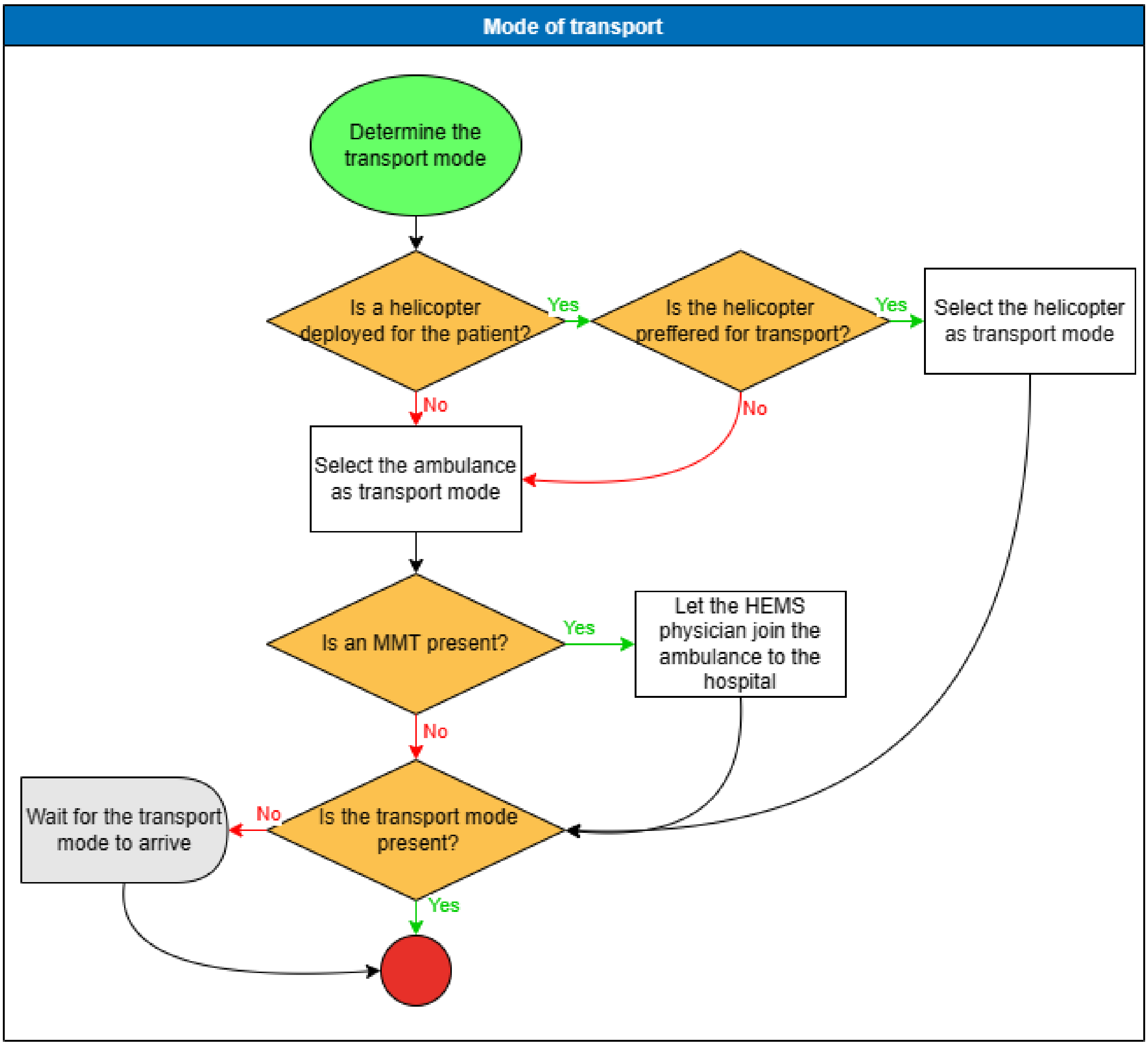

Figure 13: Flowchart of the process of choosing the transportation mode

The decision on the mode of transportation for the patient relies on the deployed vehicles and associated probabilities. Ambulances and helicopters are the only vehicles that can transport patients, thus, if no helicopter is dispatched, the patient automatically undergoes transportation by ambulance. In instances where both an ambulance and a helicopter are dispatched for a patient, the model utilizes percentages to determine the preferred mode of transport. A distinction is made based on whether the helicopter originates from the Netherlands or Germany, as the German helicopter is more frequently used for transport due to policy differences (AZEUR, 2023).

Once the transportation mode is chosen, specifically for ambulances, an additional check is performed to verify the presence of an MMT at the incident. If an MMT is present, the HEMS physician from the helicopter or ground vehicle accompanies the ambulance during the journey to the hospital. In most cases, the transport vehicle is already on-site and transportation to the hospital can commence upon completion of the treatment. In a few instances where the selected transport vehicle is not yet present, a brief wait is required until the vehicle arrives.

Sub-process: Hospital selection

The sub-process concerning the selection of the hospital is displayed in Figure 14.

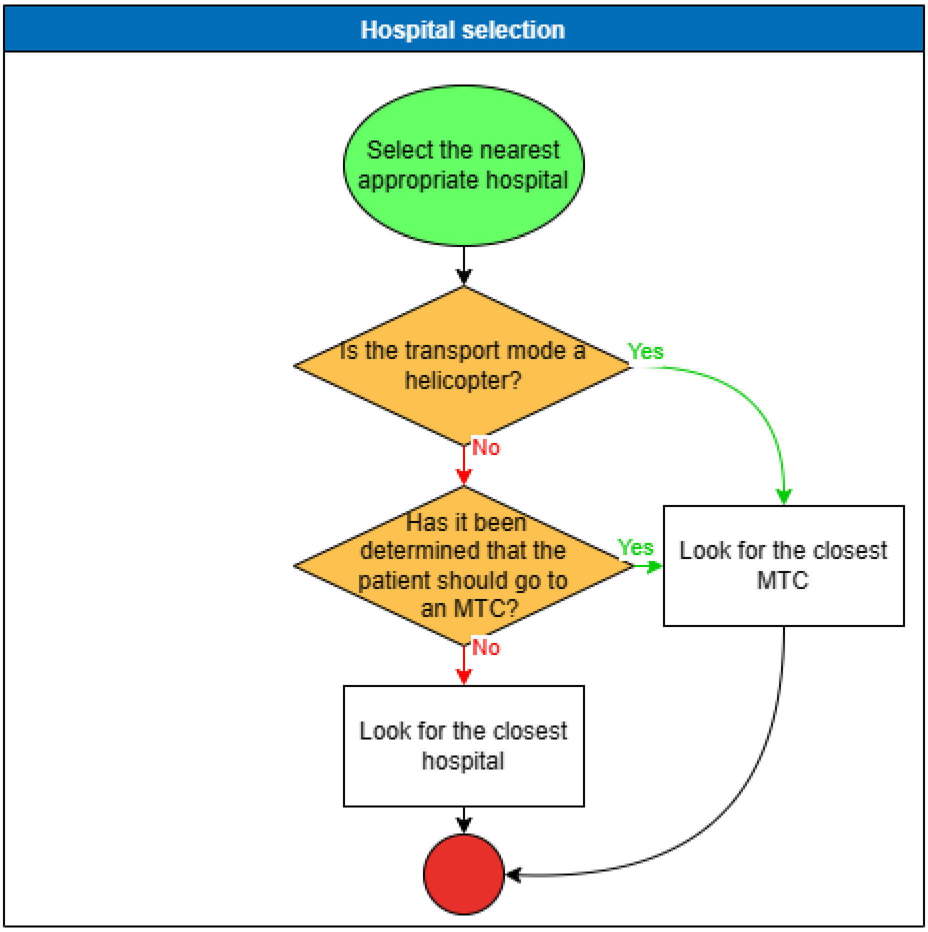

Figure 14: Flowchart of the process of selecting an appropriate hospital

The determination of whether a patient should be transported to an MTC is pre-established within the model at the time of incident generation. Even if an earlier decision suggested transporting the patient to a regional hospital, in cases where the helicopter is the chosen transport vehicle, the patient will still be directed to an MTC. The underlying assumption is that when a helicopter is used for transport, it indicates the patient's serious injuries and regional hospitals may not all be equipped for helicopter landing. Consequently, the model assumes that patients transported by helicopter should be taken to an MTC.

If the decision is made to transport the patient to an MTC, the model assesses all available MTCs and selects the one that can be reached most quickly from the incident location. Conversely, if it is determined that transporting to an MTC is not necessary, the model evaluates the nearest hospital in general, which could still be an MTC.

Sub-process: Transportation & handover

The final sub-process involves transporting the patient to the hospital and completing the handover, as illustrated in Figure 15.

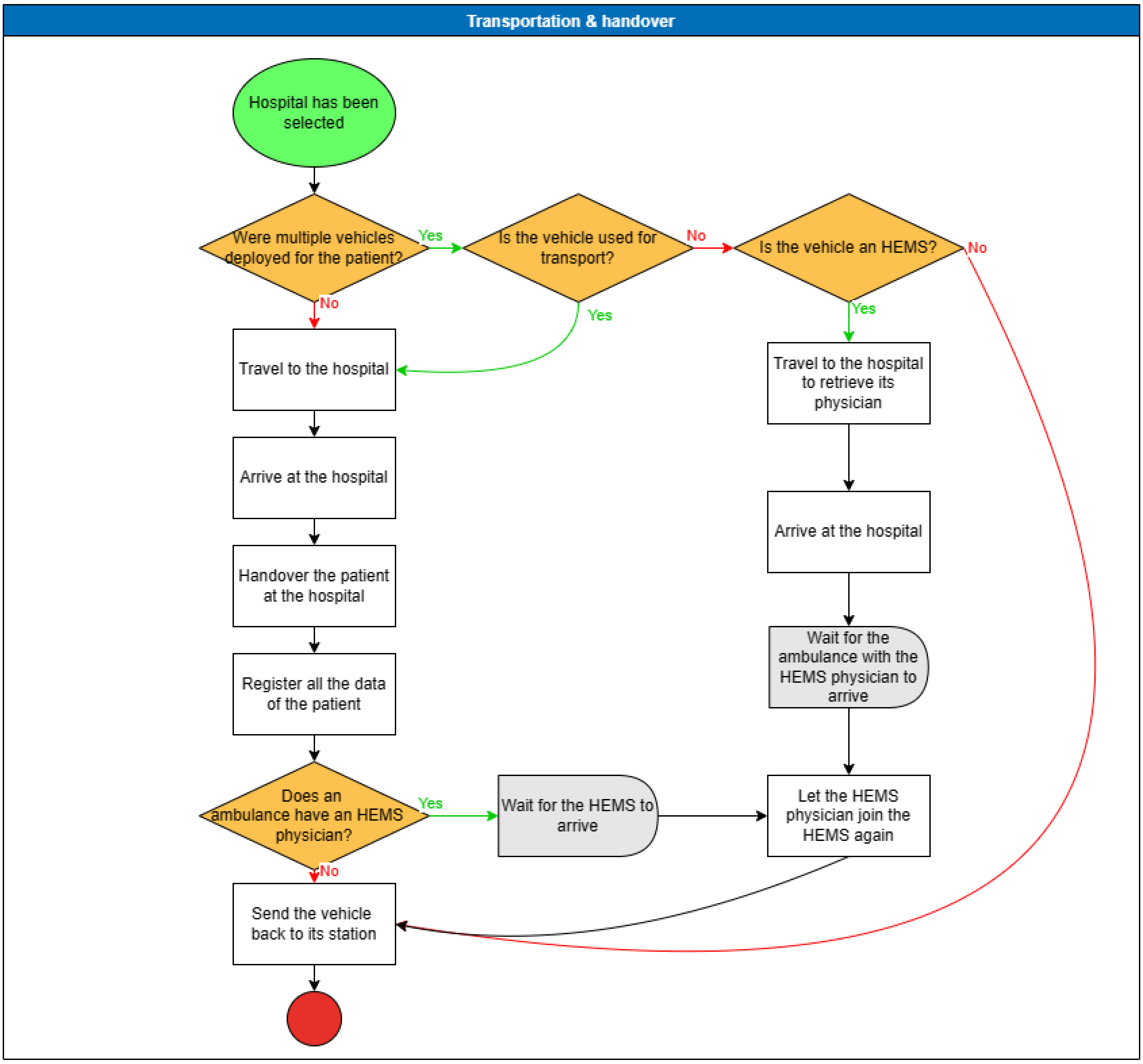

Figure 15: Flowchart of the process of transporting and handing over the patient

Once the transport vehicle and the nearest appropriate hospital are determined, the patient's transportation process is initiated. For cases where only an ambulance is deployed, the process is straightforward. The patient is loaded into the ambulance, transported to the hospital and handed over, with all patient data stored within the model. Following completion, the ambulance becomes available for other incidents and returns to its station.

When multiple vehicles are dispatched for the patient, each vehicle's role must be assessed. The transport vehicle follows a similar protocol to that described for the ambulance. The key difference arises when the transport vehicle is an ambulance and an MMT was present at the incident. In this case, the HEMS physician accompanied the ambulance to provide optimal care during transport. Once at the hospital, the HEMS physician rejoins the HEMS team and the ambulance becomes available for other incidents, returning to its station.

If a helicopter or ground vehicle is present at the incident and the ambulance is the chosen means of transport, the helicopter or ground vehicle also travels to the selected hospital to retrieve its physician, as per the model. Upon arrival at the hospital, the HEMS physician may not be immediately available, leading to a waiting period until the physician can rejoin the vehicle. This waiting scenario can occur in reverse, where the physician has finished procedures but the helicopter or ground vehicle is not yet present at the hospital. Once the team is complete again, they become available for other incidents and return to their station. An ambulance not utilized for transport is also made available again and returned to its station.

Appendix C: Validation procedure

This section provides a more in-depth explanation of the validation procedure. It includes an analysis of patient numbers, both including and excluding self-transport cases. Additionally, the methodology used to determine the required number of runs for model validation is elaborated upon. Furthermore, a range of outcomes is presented, which covers both the count of multitrauma patients in the MTCs and the score on the 90% norm between the runs.

Exclusion own transport

To exclude patients who arrived at a hospital through their own means of transport, 5% of multitrauma patients and 24.15% of the total number of trauma patients are excluded (Kramer & Leenen, 2022). Table 16 and Table 17 provide a breakdown of the number of multitrauma patients within MTCs and the total number of trauma patients within each ROAZ region considered for this research.

Table 16: Difference between in- and excluding multitrauma patients with their own transport

	Including own transport	Excluding own transport	Difference
MTC	**Multitrauma patients**	**Multitrauma patients**	**Multitrauma patients**
Vumc	179	170	-9
AMC	223	212	-11
LUMC	193	183	-10
HMC	245	233	-12
HagaZiekenhuis	104	99	-5
Erasmus MC	426	405	-21
UMC Utrecht	353	335	-18
Isala	308	293	-15
Radboud UMC	502	477	-25
ETZ	412	391	-21
Maastricht UMC+	260	247	-13
MST	306	291	-15
UMCG	350	333	-17
Total	3861	3668	-193

Table 17: Difference between in- and excluding all trauma patients with their own transport

	Including own transport	Excluding own transport	Difference
ROAZ	**Total trauma patients**	**Total trauma patients**	**Total trauma patients**
NAZNH-FL	12416	9418	-2998
NAZW	7273	5517	-1756
TCZWN	9911	7518	-2393
NAZMN	4677	3548	-1129
NAZZ	5898	4474	-1424
AZO	6777	5141	-1636
NAZB	9808	7440	-2368
NAZL	5895	4472	-1423
AZEUR	4203	3188	-1015
AZNN	7653	5805	-1848
Total	74511	56521	-17990

Number of runs

To determine the number of runs necessary for validation, the replication/deletion approach with a 95% confidence interval is used (Law, 2015). The approach initiates with an initial set of simulation runs to estimate result accuracy. Variance in these results is computed and a predetermined level of precision (in this case, 95%) is set. Using the estimated variance, additional runs are performed to attain the set precision. These runs are iterated until the precision goal is reached, ensuring trustworthy results.

Under the assumption of infinite hospital capacity, a high number of available ambulances and the simulation initiation at midnight when incident occurrences are minimal, the decision is made that no warmup period is required for the runs. This choice holds even in cases where the number of ambulances is reduced for the sensitivity analysis. The model's performance does not depend on the initial conditions, showing steady-state behavior. The replication/deletion approach is applied to the number of multitrauma patients in the MTCs and the score on the 90% norm for each ROAZ region and nationwide because these numbers reflect the trauma norms. For the score on the 90% norm, 6 runs would be sufficient but for the number of multitrauma patients in the MTCs, a total of 18 runs would be needed so that for all MTCs, the precision of 95% could be attained. Therefore, the choice is made to run the model 18 times for each scenario.

Range

Figure 16 displays boxplots illustrating the distribution of the number of multitrauma patients transported to MTCs by ambulance or helicopter over 18 simulation runs of the current situation. Variations between runs arise due to the utilization of different sequences of random numbers in each run. With a 95% confidence level, if the simulation were repeated using an alternative sequence of random numbers, the quantity of multitrauma patients within each MTC would likely fall within the range specified by the minimum and maximum values presented in Table 18.

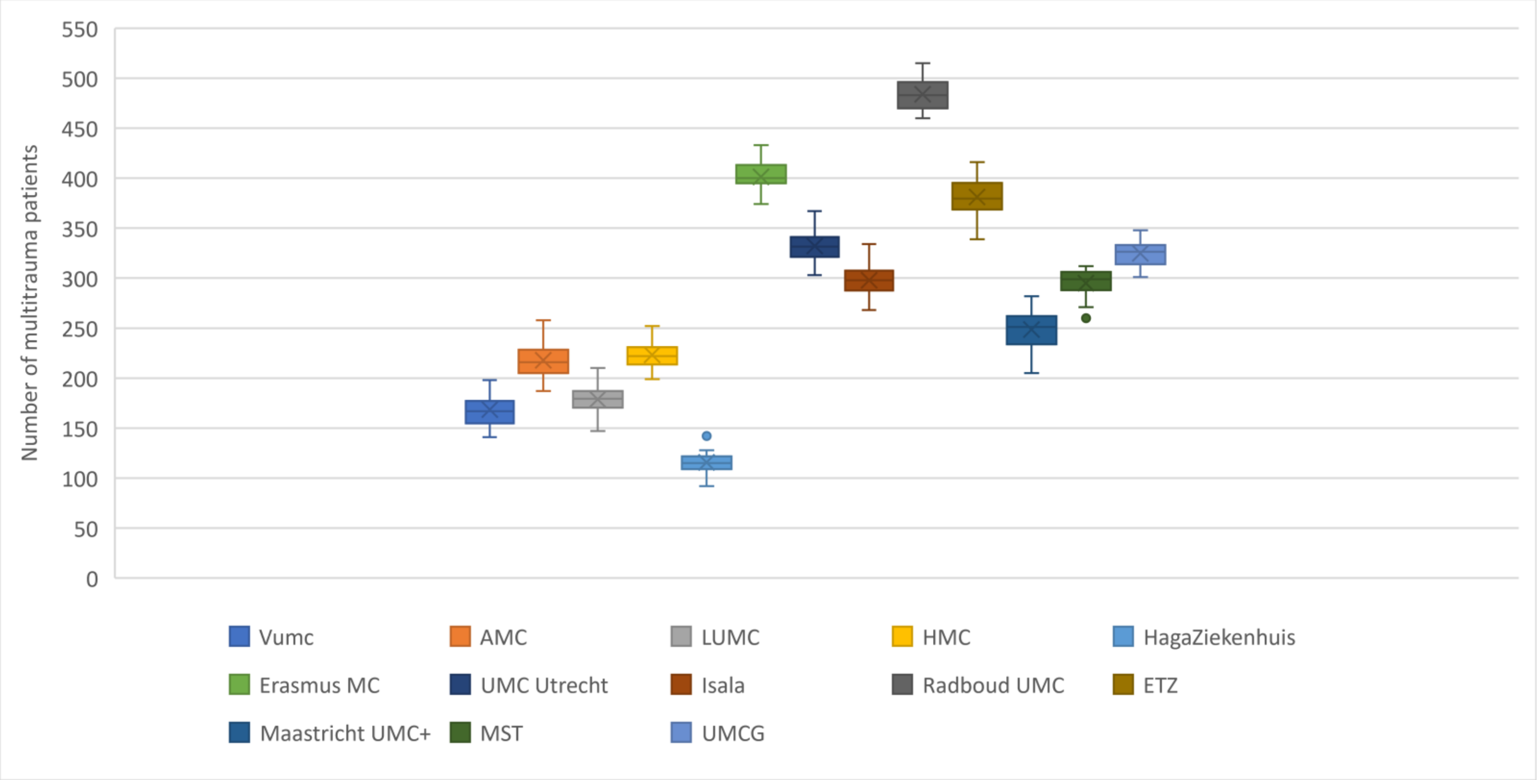

Figure 16: Number of multitrauma patients in the MTCs across simulation runs

Table 18: Min, max and the average number of multitrauma patients within the MTCs across simulation runs

	Vumc	AMC	LUMC	HMC	HagaZiekenhuis	Erasmus MC	UMC Utrecht	Isala	Radboud UMC	ETZ	Maastricht UMC+	MST	UMCG	National
Minimum	141	187	147	199	92	374	303	268	460	339	205	260	301	3586
Average	168	218	179	223	116	401	332	298	484	381	249	295	325	3669
Maximum	198	258	210	252	142	433	367	334	515	416	282	312	348	3770

Figure 17 presents boxplots that offer insights into the distribution of scores on the 90% norm across ROAZ regions and the national score. These boxplots are derived from 18 simulation runs, each representing the current situation. It's important to note that, within a single region, the scores on the 90% norm can exhibit considerable variability across different runs. In the most extreme cases, the variability may be as high as approximately 12%, as can be seen in Table 19. However, these extreme instances are outliers and the majority of scenarios tend to show much smaller fluctuations in scores. Notably, the national score remains consistently stable, exhibiting only minor variations between runs. This consistency indicates that the national performance regarding the 90% norm in the model is robust and resilient, with the overall trend being relatively unaffected by random numbers.

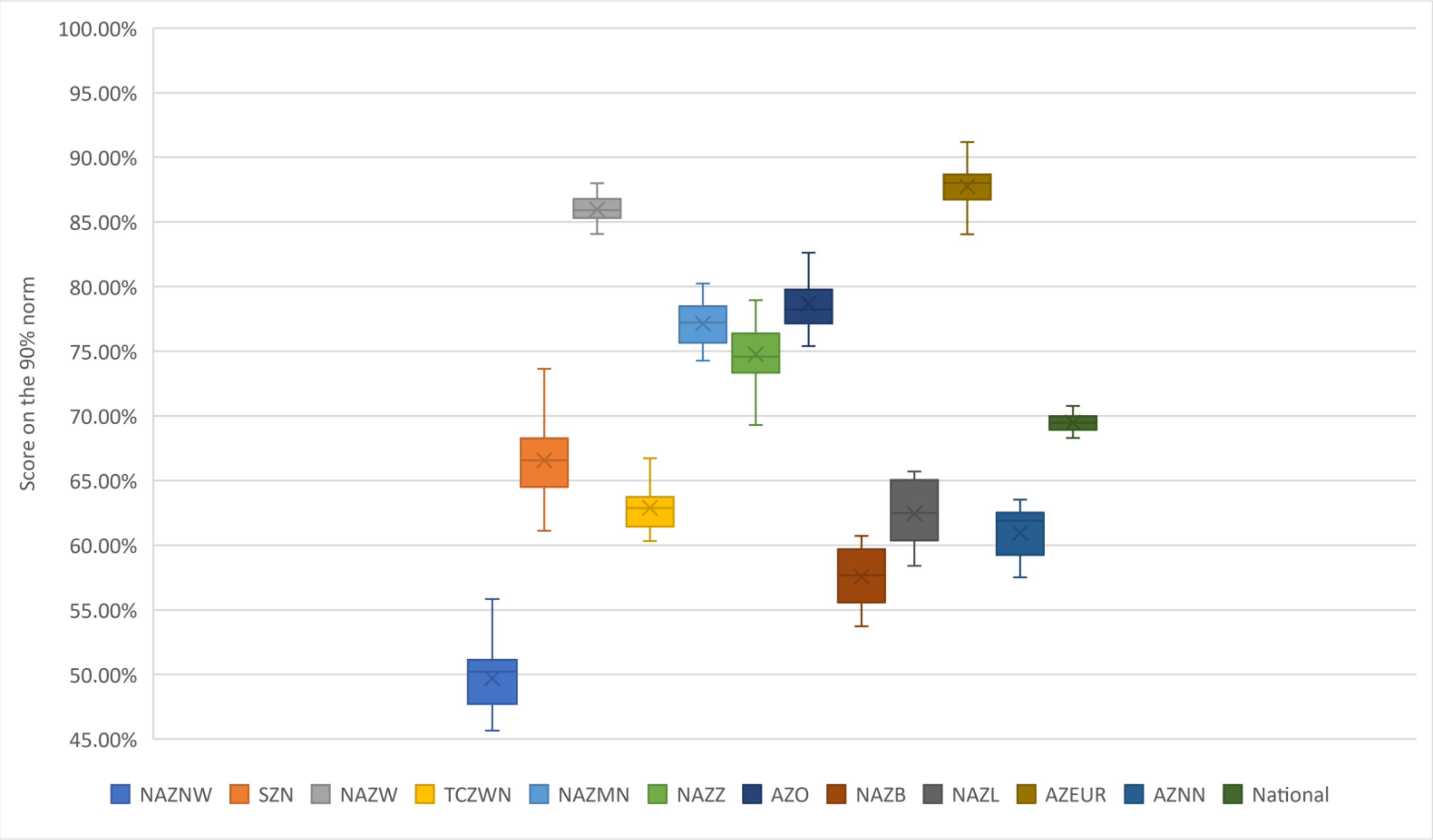

Figure 17: Score on the 90% norm across simulation runs

Table 19: Min, max and the average score on the 90% norm across simulation runs

	NAZNW	SZN	NAZW	TCZWN	NAZMN	NAZZ	AZO	NAZB	NAZL	AZEUR	AZNN	National
Minimum	45.67%	61.11%	84.07%	60.32%	74.29%	69.30%	75.40%	53.72%	58.40%	84.06%	57.51%	68.29%
Average	49.71%	66.57%	85.96%	62.88%	77.14%	74.76%	78.68%	57.56%	62.44%	87.74%	60.95%	69.49%
Maximum	55.84%	73.65%	87.99%	66.72%	80.24%	78.96%	82.62%	60.72%	65.69%	91.19%	63.53%	70.76%