Bachelor Thesis

The allocation of patients to hospitals in case of a disaster

A mathematical model

E.M. Draijer
3-8-2017

UNIVERSITY OF TWENTE.

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Industrial Engineering Management
Faculty of Behavioural, Management and Social Sciences
August, 3, 2017

Student
E.M. Draijer

Supervisors
Dr. D. Demirtas (first supervisor University of Twente)
Dr. ir. L.L.M. van der Wegen (second supervisor University of Twente)
Dr. ir. N.C.W. ter Bogt (mentor Acute Zorg Euregio)

University
University of Twente
Drienerlolaan 5
7522 NB Enschede

Preface

Hereby I present to you my bachelor thesis. This thesis is the end of my bachelor Industrial Engineering Management. This research is commissioned by and in collaboration with Acute Zorg Euregio. In this preface I want to thank a few people.

First of all, I want to thank the staff of Acute Zorg Euregio. Nancy and Rolf, thank you for the opportunity to conduct this research and thank you for all the tips and support. You made me enthusiastic about and realise the importance of cross-border care.

Second, I want to thank a few people from the University of Twente. Derya, thank you for your advice and your constructive feedback as first supervisor. Leo, thank you for your wisdom and critical feedback.

E.M. Draijer

August 2017

Summary

Motive
Acute Zorg Euregio is one of the eleven emergency care networks in the Netherlands. One of their roles is to create a network of chain partners that are involved in emergency care, such as hospitals, regional ambulance services, mental health and midwives. To train what to do when a disaster happens, Acute Zorg Euregio held various trainings with the Emergo Train System (ETS). These trainings made them realise that improvement can be made in the field of disaster planning. They were curious if a mathematical model could improve the allocation of patients to a hospital in case of a mass casualty incident.

Method and conclusion
Linear programming (LP) is concerned with describing the interrelations of the components in a system[13]. Using an Integer Linear Programming model to assign patients to hospitals we draw the following conclusions: comparing the results of the mathematical model to the results of the exercise of 2016, we see that for all triage levels the average arrival time in the hospital can be shortened by 10 minutes. In addition, the number of hospitals involved in the disaster is reduced and both the sum of all travel times and the time when the last persons arrive at a hospital are shortened.

In addition to the scenario of the exercises, also different scenarios were implemented in the model to see what happens if different choices were made in the values of the input parameters. These scenarios range from what if an extra helicopter was deployed to what if all patients with a T1 triage must go to a Level 1 hospital. Based on these scenarios we conclude that helicopters do not attribute much to lower the travel times for patients. On the other hand, having a hospital less has little negative impact but forcing each T1 patient to go to a Level 1 hospital has great, negative, impact.

Recommendations
Based on this research, we give recommendations on three different dimensions. First, on the allocation of patients to hospitals, second, on the ETS exercises and third, on further research.

The allocation of patients to hospitals in case of a disaster can be improved by sending patients not too far. The idea of a Major accident Hospital is nice, but the distance from the disaster scene to this hospital is big in this scenario. Second, the use of helicopters instead of ambulances do not contribute largely to the speed of distributing patients to a hospital in case of a mass casualty incident. At this moment, it is common that helicopters distribute the patient to the hospital the helicopter belongs to, but we advise that, if the helicopters fly, the helicopters do not go to the destination of their origin with the patient, but to a hospital close to the disaster scene.

Since the ETS exercises were the motive for this research and these exercises were not a way to collect data for this research, some information was missing. For example the time when a patient is ready for transport and the patients who had to be freed by the fire brigade. If more ETS exercises are held, we advise them to collect and write down more data. In addition, we advise that the role of the ETS leader is to check whether everything goes according to the rules and to answer questions if anything is unclear for the participants. He/She should not change any decisions of the participants. Last, we advise them to use the same input values for all exercises, so to use the same capacity, ambulances and travel times instead of making a new starting point for each exercise.

Further research on this project is advised to implement waiting times for patients and to let ambulances return to the disaster scene. This will have big influences on the times when patients arrive in a hospital and probably less ambulances are used. A second option is to make a model where patients are assigned one by one, using a formula so the ambulance personnel can know if they need to drive to the closest hospital or a hospital further away.

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1. Introduction

This first chapter provides an overview of the company Acute Zorg Euregio in Section 1.1, the Emergo Train System in Section 1.2, triage in Section 1.3, motivation for this research in Section 1.4, and the research questions in Section 1.5.

1.1 Acute Zorg Euregio

When a patient suddenly needs care, it is important that he/she gets the right medical treatment at the right place. When there is just one patient a hospital should be able to handle it. However when a disaster happens, the other hospitals in the region or outside the region need to help. To aid this process, the Dutch government created eleven emergency care networks *(trauma centrums)*. One of the core tasks of these emergency care networks is to create a network of chain partners that are involved in emergency care, such as hospitals, regional ambulance services, mental health and midwives[1]. The goal of this connection is to have a better collaboration when emergency care is needed.

One of the eleven emergency care networks is called *Acute Zorg Euregio* (AZE). This network is responsible for the Dutch areas *Twente* and *Oost Achterhoek*[2]*.* In addition, there is a close collaboration in the border area with the German areas *Landkreis Grafschaft Bentheim, Kreis Borken* and *Kreis Steinfurt*. Figure 1 shows the chain partners of AZE. To prepare these chain partners for a major incident AZE uses OTO (educate, train and practice; *opleiden, trainen en oefenen)*[2]. One way to simulate the disaster scenarios is through the Emergo Train System.

Figure 1 Chain partners Euregio

1.2 Emergo Train System

The Emergo Train System (ETS) is a worldwide used “simulation system used for education and training in emergency and disaster management” developed in Sweden[3]. The system solely consists of a magnet board and different kinds of magnets. For example, each victim of the disaster has an identification number and human-shaped magnet with information on it (see Figure 2). In the front of the magnet the information is shown that is visible (such as gender, making sounds and standing/sitting/lying) and at the back the information that can be quickly asked or measured is stated. In addition to the magnet board, other tables and tools are used to simulate the disaster as realistically as possible. More information about the Emergo Train System can be found in Chapter 2.

Figure 2 Emergo Train System patients

1.3 Triage and Levels

Triage is 'a process in which a group of patients is sorted according to their need for care'[4]. In case of a disaster the ambulance staff investigates how severely a victim is injured by categorizing him/her in a category arranging from T1 to T3. T1 consists of the most severely injured people and T3 are people who can still walk.

Since 2012 the NVT, the Dutch Association for Trauma Surgery (*Nederlandse Vereniging voor Traumachirurgie*) established rules to determine the level of resources for each hospital[5]. Three levels exist: level 1, level 2, and level 3. A level 3 hospital can treat isolated injuries, while a level 2 hospital can also treat patients with vital threats. A level 2 hospital only misses some facilities, for example a neurosurgery department. These facilities are present in a level 1 hospital, making these hospitals able to treat all seriously injured patients.

People with a T1 indication who have a neurological disorder or are polytrauma, need to go to a level 1 hospital[5]. Neurological disorders are disorders of the nervous system[6] and polytrauma means that a victim has multiple injuries[7]. People with a 'normal' T1 or T2 indication can go to a level 1 or level 2 hospital and people with a T3 indication are, in case of a disaster, mostly treated at the scene but can also be treated by a general physician or in a hospital at a later moment. This is summarized in Figure 3.

Triage of patient	Where the treatment has to be
T1 – neurological and/or polytrauma	Level 1 hospital
T1 – not neurological or polytrauma	Level 1, 2 or 3 hospital
T2	Level 1, 2 or 3 hospital
T3	At the disaster scene

Figure 3: Triage – level connection

1.4 The motive

To simulate disaster scenarios, Acute Zorg Euregio has done two exercises with the Emergo Train System. The results of the exercises were different in terms of triage, treatment at the stage, use of recourses, assignment and transport, resulting in different times when all patients are in a hospital. In terms of assignment, 10 hospitals were used in both exercises, 3 hospitals were used in only the first exercises and 6 hospitals were used in the second exercise. A visual representation can be found in Appendix 1. As can be seen in this figure, the German hospitals are only used in Exercise 1. The Major accident Hospital is used in both exercises.

The differences in the exercises made AZE wonder what the optimal solution for the current scenario (such as in 2016) looks like. An optimal solution is important, because patients need treatment as soon as possible. In the worst case scenario, late treatment can cost lives, because it is possible that a patient is treated later than he/she should be and dies in the meantime.

Therefore, we look for a computer solution that improves the assignment from patients to a hospital. A computer can weight decision criteria consistently and can do a lot of calculations in the short period of time available. This research adds knowledge to the field of disaster planning to make the survival rate higher.

1.5 Research questions

We define the main research question as follows:

How can the patient assignments from a patient to the most suitable hospitals be improved in case of a disaster?

To answer this question, we first need to investigate how the assignment of patients to hospitals is done during the exercises and how it is done in real life. After this is done, a suitable method is searched to improve the assignment. Then we implement this method to the first case and to other scenarios to find a solution. Last, we draw conclusions and recommendations based on this research.

These plans give us the following research questions:

1. How are the ETS exercises conducted?
    a. What is the difference between the exercises?
    b. How is the input (resources and patients) mapped?
    c. What is the output of the exercises?
2. How are patients currently in real life assigned to the most suitable hospital in case of a disaster?
    a. Who makes the choice to assign the patients to the hospitals?
    b. How are the resources (number of ambulances, helicopters and hospitals) mapped?
    c. How is the hospital where the patient will be assigned to chosen?
    d. How can this information be used in this research?
3. What method can be used to assign patients to the most suitable hospital in case of a disaster?
    a. How could it be adopted to this problem?
4. How can the model to improve the allocation of a patient to the most suitable hospital after a disaster be formulated?
    a. What is the input for this model?
    b. What are the parameters, the objective and the constraints?
    c. What is the solution when using the data from the ETS handbook of 2016?
    d. What are the solutions if other input data is used?
5. What are the insights and suggestions from this model to improve the assignment?

Each research question is covered in another chapter.

2. Emergo Train System

In this chapter the Emergo Train System is further explained. The materials are explained in Section 2.1, the input of the ETS in Section 2.2, how the exercises are conducted in Section 2.3, the similarities and differences between the two exercises in Section 2.4 and the output in Section 2.5. Section 2.6 gives a conclusion of this chapter.

2.1 Materials of the ETS

As stated in Section 1.2, the Emergo Train System is a system to simulate disaster scenarios. At the start of the exercise, various magnet boards are placed full of patients, ambulances and ambulance personnel, as can be seen in Figure 4. The warning tape at the top of the board is a symbol for the part of the disaster scene which is not accessed yet.

The people behind the table are 112 operators. These operators have documents with available resources and a phone to receive the 112 call.

Other people were responsible for tracking time to be able to calculate results. They also took care that the ambulances travelled the times as stated in the handbook.

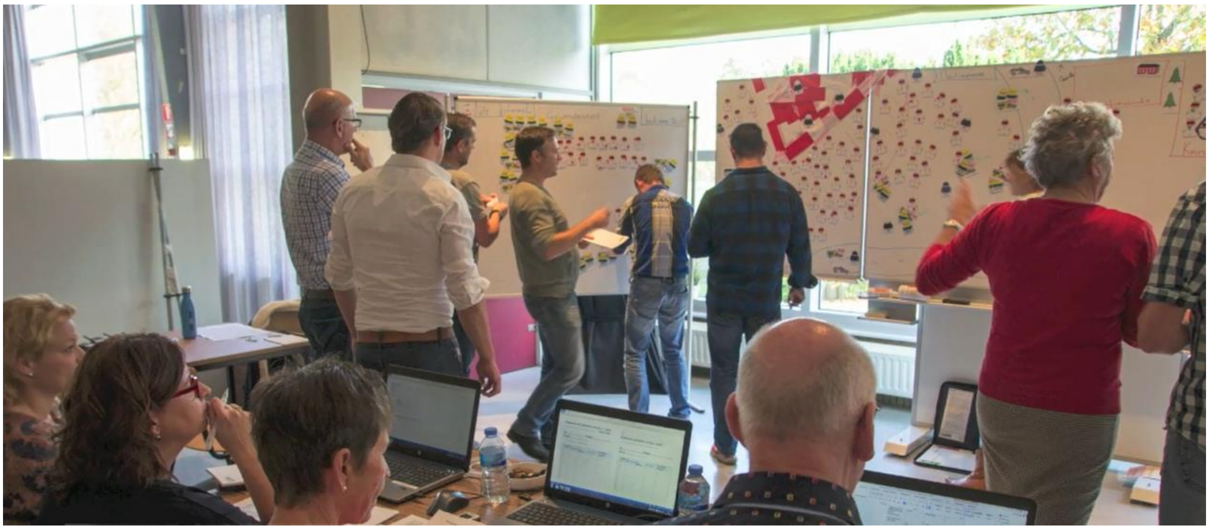

Figure 4: Emergo Train System

2.2 Input: patients and resources

All patients have a number in the ETS exercise. Before the exercise takes place, the leader decides which patients are included in the exercise. These patients are partly placed at the big magnet board and the other part is placed at another board to simulate the dangerous zone. This distinction is not registered (neither beforehand, nor during the exercise). The ETS leader knows which triage each patient officially has, but the people who do the exercise do the triage themselves.

In the ETS exercise, the travel time for both the ambulances and the helicopters from the disaster scene to the different hospitals are fixed. For the ambulances there is a difference between traveling with and without siren. In real life the travel time depends on many factors, such as weather, traffic accidents, quality of the roads and traffic conditions[8]. To determine the travel time without lights and siren from the disaster scene in the ETS exercises (Holtdijk, Goor) to the hospitals, the shortest travel time according to Google Maps is used. Research[9] has shown that Google maps is an accurate method for route-based transport time estimation.

To determine the travel time with an ambulance with lights and siren, the normal travel time is multiplied with a factor 0.7 in the exercises. Different studies are conducted about the savings in travel time by using lights and siren[10,11]. Ho et al.[10] found an average significant time saving of 38.5% in traveling with lights and siren compared to traveling without them. Other research[11] has found that the mean transport time without lights and siren increased by 35% over transport time with lights and siren. Based on these researches, the 30% reduction in the ETS seems a bit conservative. However, both researches are conducted in other geographical areas which can make a difference. Finally, to be able to compare the model we design with the exercise from 2016, we also use the 30% reduction in this model.

The number of T1 and T2 patients a hospital can treat per hour is determined by the hospitals themselves. To determine the capacities in the ETS exercises, the leader consulted the hospitals beforehand and asked if their capacities were up-to-date. In the exercises these capacities are passed on to the dispatch centre and the dispatch centre uses these values to determine how many patients can go to each hospital. However, still there are some doubts whether the capacities are correct or not, because some level 2 hospitals have a bigger capacity than a level 1 hospital. The capacities are defined as 'T1 per hour' and 'Total patients per hour'. A maximum for a longer period is not stated, even though some capacities run out when the maximum capacity is used for a long time, for example SEH (emergency department, s*poedeisende hulp*) beds. Therefore, in real life the capacity of a hospital fluctuates over time: sometimes a hospital has a crowded SEH, while a little while later the SEH is nearly empty. Although the dispatch centre is aware of this fact, the capacity is not actively monitored. The hospital must prevent the demand being higher than what the hospital can offer by contacting the dispatch centre.

2.3 Conducting the exercise

The team that is doing the exercise needs to decide what to do with each magnet. Depending on how severely the patient is injured, the patient needs to be placed in a local accommodation or needs to go to a hospital. To simulate this as realistically as possible, a small group of ambulance nurses take part in the exercise. They sort the patients one by one based on their need of care (triage). If a victim is severely injured, the patient gets a red T1 label. A less severely injured patient gets a yellow T2 label and a victim who is still able to walk gets a green T3 label. Patients who passed away are not included in the exercises. During the exercise, the patient does not switch between the triage levels and also patients do not die.

In the beginning of the exercise a few patients are placed on another board to simulate the unsafe area. One person keeps track on time and sets these patients free by placing them on the main board. As soon as they are on the main board they are treated like a regular patient.

When an ambulance for transport arrives, it should also be decided to which hospital each patient should be assigned to by the 112 operators. Also the choice to call a trauma helicopter is possible. First, the patients with a red label are one by one assigned and transported. The 'runner', who is responsible for moving the patients during the exercise, takes the magnet of the magnet board and walks to the table with 112 operators. These operators decide to which hospital each patient goes. The patient with his/her ambulance is placed on another board and when the time that an ambulance can be back at the scene, the ambulance is set free and is able to distribute patients again.

2.4 The two exercises

Two exercises were conducted. The first took place in November 2015 and the second in December 2016. In 2015 the GHOR (Medical Assistance Organisation in the region, *Geneeskundige Hulpverleningsorganisatie in de regio*) was responsible for the coordination in case of a major incident[4]. This method is called GNK-c (medical combination, *Geneeskundige combinatie*). All patients were treated or stabilized on scene as much as possible ("stay and play"). Since January 1, 2016 the GHOR is no longer responsible for the coordination after a major incident, but the RAV (Regional Ambulance Service, *Reginale ambulance voorziening)* is. This method, which is called GGB (Large-scale Medical Assistance, *Grootschalige Geneeskundige Bijstand*), aims to distribute the serious injured people (T1 and T2, see Section 1.6) as quickly as possible to the hospital ("scoop and run"), while the less injured people are treated by the emergency teams of the Red Cross at the scene. This method was used in the second exercise in December 2016.

Besides the method and the responsibility there were many more differences. Before each exercise the leader set a baseline measurement for the capacities of the hospitals, travel times and the number of ambulances and helicopters available. This baseline was different for the different exercises. This means that the resources were different (number of ambulances, arrival times, transport times and capacity of the hospitals). In addition, the patients are not totally the same; the triage (as set by the ETS in Sweden) is the same but the injuries are not.

2.5 Output

When there is no injured person left at the scene of the disaster, it is possible to calculate and summarize the patient outcome as can be seen in Appendix 2. In the exercises, the key performance indicators (KPIs) regarding allocation of patients are (a) when the last ambulance is free (when the last patient arrives in the hospital), (b) how many ambulance are used, (c) how many ambulances are used twice, (d) how many ambulance travels are made and (e) the number of hospitals involved. In addition, there are also some KPIs that focus on what happens at the stage: (a) when the last T1 patient leaves the disaster scene, (b) when the last T2 patient leaves the disaster scene and (c) the number of T1 and T2 patients. Using this KPI's, the KPI's of the model are determined. These are described in Section 5.6

2.6 Conclusion

The Emergo Train System is a way to practice what ambulance personnel and 112 operators must do in case of a disaster. Using a magnet board and various kinds of magnets, the disaster scene is simulated. Two ETS exercises are held to map the differences between the two methods which were used in real life when the exercises were held. At the start of each exercise, the ETS leader determines the capacities of the hospitals and the ambulances. During the exercises, the patients get a triage level and are assigned to a hospital. This, and some of the times, are written down in an excel sheet and calculated into KPI's. It is important to know how the ETS exercises went, because a lot of data and how the exercises go is used in the model.

3. Current situation

*This chapter answers the second research question '*How are patients currently assigned to the most suitable hospital in case of a disaster?'. *Each section gives answers to one of the sub questions. Section 3.1 states who is involved in assigning patients to a hospital. Section 3.2 is about the resources and how their availability is collected. Section 3.3 is about the actual assignment and Section 3.4 defines what is useful for this research. Last, Section 3.5 gives the conclusions of this chapter.*

3.1 Responsibility

When an emergency call arrives in the despatch centre, the 112 operator quickly indicates what the scale of the incident is. In case a disaster happened, the 112 operator does not handle the case himself/herself but an extra 112 operator and the "buddy meldkamer", the collaborating despatch centre, help. In addition, there is also contact with the police and fire brigade.

The extra 112 operator is responsible for the contact of transport. This person tells each ambulance to which hospital they should go. This person also keeps track of the capacity of the hospitals.

3.2 Resources

It is important to know which hospitals, ambulances and helicopters are available when assigning the patients. The 112 operator receives the information in different ways.

3.2.1 Hospital capacity

At any point in time, the MBC (medical treatment capacity/*medisch behandel capacity)* is known for each hospital: the number of patients per triage level that they can treat per hour. The buddy despatch centre starts calling hospitals as soon as they read in GMS (communal despatch centre system/*gemeenschappelijk meldkamer systeem*) that a disaster took/takes place. Each hospital sends the buddy despatch centre its own actual MBC.

A special hospital is the Major accident Hospital (*calamiteiten hospitaal).* This hospital is located under the Level 1 hospital UMC in Utrecht. The Major accident Hospital has lots of capacity, but when patients come to this Level 1 hospital, the UMC cannot take any patients to the first aid due to staff constraints. Another constraint is that if there are patients assigned to this hospital, there must be at least five patients.

3.2.2 Ambulances

The 112 operator sends the first ambulance to the disaster scene immediately. Depending on the (estimated) number of victims (received by the caller and/or the ambulance), the 112 operator sets out a code alert, such as code 10. The number of ambulances that are used are based on this code. However, this is a guide line, not a strict rule. When asking ambulances to help, it is important that enough ambulances are still available to cover the region. Ambulances of other regions are used when the region is not able to handle it themselves. Sometimes the role of these out-region ambulances is to cover the region, in other cases they are used at the disaster scene.

The driver and the nurse of the ambulance decide if the ambulance is going to ride with lights and siren him-/herself, because the nurse can indicate the stability of the patient and the driver can indicate how crowded the road is. The ambulance personnel has to request for permission to drive with lights and siren at the despatch centre, but this permission is almost always given. When an ambulance needs to go back to the disaster scene to help another patient, it is also possible to ride with lights and siren, because then they arrive earlier to help other patients.

3.2.3 Helicopters

The LifeLiners, the trauma helicopters, are only able to fly under certain conditions. For example, they cannot fly when it is foggy and the German helicopters do not fly at night. Depending on the place of the disaster and the availability of the helicopters the helicopter is chosen. The pilot, nurse and physician of the helicopter have two options when they arrive at the stage. First of all, they can choose to transport a patient to a hospital. The second option is to help at the disaster scene. The physician can do proceedings that an ambulance nurse cannot do, such as intubation. The choice between these two options is made based on the situation and the kind of injuries. In case of a disaster, most of the time the physician stays at the disaster scene as long as possible. Most of the time, the helicopters return to the same place where they come from but sometimes invention about the destination is necessary when a disaster happened.

3.3 Assignment

The first ambulance that arrives at the disaster scene starts to triage the victims. When the next ambulances arrive at the disaster scene, they help the severely injured people first.

The 112 operator takes many factors into consideration when assigning the patient to a hospital. For example the medical treatment capacity, the level of the hospital and the patient. The state of the patient, triage and stability, makes the 112 operator decide what level hospital the patient needs. Besides, depending on the number of patients and how severely a patient is injured, the ambulance is traveling far or close. A German ambulance can better go back to a German hospital, because the driver knows how to drive and communication is easier. The number of available ambulances also has to be taken into account. For example, maybe it is better when you send a stable T2 patient to a hospital nearby, because then the ambulance is back earlier. Because a ride is stressful for a patient, it is important that a patient is assigned to the right hospital immediately, wherefore an extra ambulance for interclinical transport is not needed. For a T1 patient it is most important that definite care is provided as soon as possible, because the vital functions of that person are severely threatened.

The factors above are not the only ones. A lot of choices depend on the situation of the incident. For example, when a lot of victims are children, it is different than when it are adults. Besides the kind of incident makes a difference. When a lot of people need to be freed by the fire brigade, it can take more than 45 minutes before the first severely injured people can be assigned to a hospital. Then it might be better to first assign less injured people to hospitals.

3.4 Utility for this research

Both the ETS exercises and how patients are currently assigned to a hospital influence the model. The model we make starts at the moment the first patient is ready for transport. This means that the capacities are already known and the patients are already assigned to ambulances. However, the model can, instead of assigning the patients to the ambulances, also choose for a helicopter. The data from the ETS exercise of 2016 are used to determine the capacities of the hospitals, the times the patients are ready for transport and the travel times from the disaster scene to the hospital. For the helicopters we assume that the conditions are good, so they are able to fly. These assumptions were also made during the exercises.

The triage level per patient differs between the ETS exercise and how it was stated by the ETS developers. In the model, the triage levels of the exercise are used, because that reflects reality in the best way. However, the triage level does not determine if a patient needs to go to a Level 1 hospital. The rules in the Nationwide protocol ambulance care (*Landelijk protocol ambulancezorg)*[12] about which patient needs to go to which level of hospital are used to determine if a patient needs to go to a Level 1 hospital in the model. This protocol, which is also used in the exercises and in real life, can be seen in Figure 5.

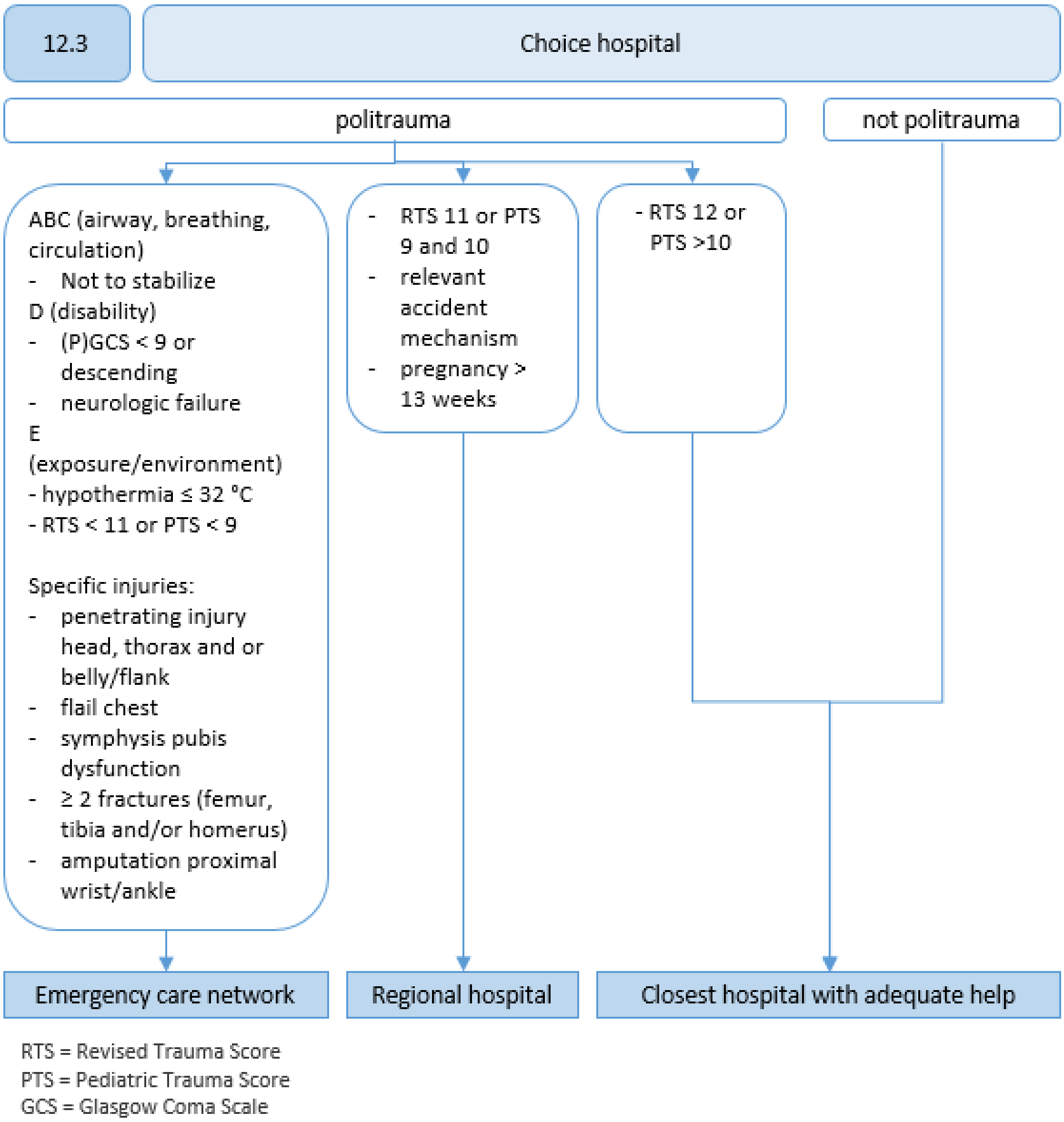

Figure 5: National protocol ambulance care

3.5 Conclusion

In case of a disaster, the 112 operator in the dispatch centre is responsible for assigning patients to hospitals. Before this happens, the buddy dispatch centre calls all hospitals to ask if their medical treatment capacity is up-to-date. The 112 operator in the dispatch centre chooses which hospital the patients is assigned to on basis of a lot of criteria. Besides the medical treatment capacity, among other things, the stability of the patient, how severely the patient is injured and how many other patients need to be transported are taken into account. How patients are currently in real life are assigned to a hospital is important to know, because these guidelines and rules can be implemented in the model. However, it is important to realise that each disaster is different causing different priorities and choices.

4. Literature review

Chapter 4 contains a motive for the method that is going to be used in Section 4.1. This method is explained in Section 4.2. Section 4.3 states what we learned of other articles about the allocation of patients after a disaster. Last, Section 4.4 gives a conclusion of this chapter.

4.1 Method

There are different ways to make a model. There are two characteristics of this case that made us choose for linear programming. First, this research has an aim to make a model to calculate the optimal way to assign patients to a hospital in case of a disaster. In addition, the input is deterministic: all input is fixed and nothing is stochastic. Last, the constraints depends on one of a summation of choices, not a product of choices, which makes the constrains linear.

4.2 Linear programming

Linear programming (LP) is concerned with describing the interrelations of the components in a system[13]. LP is a way to calculate the optimal (minimum or maximum) value of a linear problem. The LP problem consists mainly out of three parts: the decision variables, objective function and the constraints.

4.2.1 Decision variables

The decision variables are the variables you are able to change. Besides normal LP programming, three variants exists. The first variant is integer linear programming (ILP). In these kind of programming, all variables are integer (0, 1, 2, etc.). An example of an integer variable is the number of machines you are going to use, because you cannot use a half machine. A second variant is a mixed integer linear programming (MILP). In contrast to an ILP some variables are integers and some are continuous. The third variant uses binary variables (only 0 and 1) as decision variables, for example when you do (=1) or do not (=0) invest in a new plant.

4.2.2 Objective function

The objective function is the function you want to minimize or maximize. The most used objective function is the minimisation of costs. The objective function is a formula that consists of decision variables, so when the decision variables change, the objective function also changes. In many cases, there is more than one objective inherent in the problem[14]. In these cases, a multicriteria decision making problem can be formulated with weights assigned to several objectives.

4.2.3 Constraints

In solving an LP problem there must be some restrictions when only certain values of decision variables are possible, for example the maximal number of machines you can use is 5. This kind of restrictions need to be translated to constraints. The constraints are formulas that contain the equals sign (=), the smaller than or equal to sign (≤) and the greater than or equal to sign (≥). Besides, the types of numbers that are mentioned above, such as binary numbers, need to be stated in the constraints section.

4.2.4 Solve an LP

Solving an (I)LP problem can be done using several programs. One of these programs is by using Microsoft Excel and then implementing a (free) solver. The choice between the different programs depends on what the stakeholders want and the constraints of each program. Excel Solver can handle fewer decision variables and constraints than, for example, Lingo or COIN-OR. To solve the problems in this research we use COIN-OR, because Excel cannot deal with the number of constraints from this model.

4.3 Literature

Multiple articles are found about the allocation of patients to a hospital after a disaster [15,16,17,18,19]. All models of the articles aim to do the best for the patients, but the way in which this can be achieved differs. Some focused on the minimisation of impropriate hospital allocation and the capacity of the hospitals[15], while another focused on the maximizing of the number of patients that reached a trauma centre within a specified period of time[16] or on minimizing the expected fatalities[17].

In addition to the different objective functions, also the parameters differ. All articles found included the capacity of the hospitals but one took the real-time capacity and added treatment specializations[18]. Another example of different parameters is self-presenting of T3 patients that some articles[15,17] did take into account and others did not[16,19].

Reading the articles made us aware how many options there are to model the allocation of patients and made us look critical to our own objective. Our objective is stated in the next chapter. Since the ETS exercises already have parameters, reading the parameters in the articles was less inspiring, but it confirmed the importance of our parameters.

4.4 Conclusion

The method we use for making the patient to hospital allocation is integer linear programming. Using decision variables, an objective function and constraints, we want to do best for the patients. After a literature review we found that there are many ways to do best for the patients. The next chapter gives our integer linear programming model.

5. The model

This chapter contains the model. In the first section, the input values are explained and in Section 5.2 the data used for the input values are declared. In Section 5.3 the decision variables, in Section 5.4 the objective function and in Section 5.5 the constraints are stated. Section 5.6 contains the key performance indicators and Section 5.7 the solution. Section 5.8 gives solutions for other scenarios and 5.9 contains the conclusion of this chapter.

5.1 Input values

The model needs values for the input. In Section 5.1.1 the parameters are explained and in Section 5.1.2 the subsets are formed.

5.1.1 Parameters

Hospital departments: set H = {1, 2, 3, … 64}
Each hospital has two numbers, one for the T1-department and one for the T2-department. Besides, the hospitals have the following input parameters:

- C_h = Capacity T1 patients per hour for Dutch hospitals
- D_h = Total capacity patients per hour for Dutch hospitals
- B_h = Capacity T1 patients per day for German hospitals
- F_h = Total capacity patients per day for German hospitals
- K_{hv} = Travel time to hospital h with vehicle v
    - 12:49 is equal to t=0
    - Unit: minutes

Patients: Set I = {1, 2, 3, …, 102}

- E_i = Triage level: {0, 1, 2}
- J_i = Time ready for transport: J_i
    - 12:49 is equal to t=0
    - Unit: minutes

Kind of vehicle: Set V = {1, 2}
The model chooses if a patient is distributed with an ambulance (v=1) or with a helicopter (v=2).

- U_z= Capacity of helicopter depending on z
    - z makes the time intervals

5.1.2 Sets

Some constraints apply only for certain hospitals or patients. Therefore, some sets are created.

Subsets of H:

- Set $T1\ hospital\ departments\ T1H = \{1,2,3,\ldots,32\}$
- Set $T2\ hospital\ departments\ T2H = \{33,34,35,\ldots,64\}$
- Set $Level\ 1\ hospital\ departments: L1H = \{2,4,19,24,28,29,30,31\}$
- Set $German\ hospitals\ departments: GeH = \{31,32,63,64\}$
- Set $Major\ accident\ hospital\ departments: MaH = \{30,62\}$

Subsets of I:

- Sets of patients in each hour: $S_z = \{i:\ 5z \le J_i \le 5z + 59\}$
    - z = {0, 1, …, 22}
    - To simulate a rolling horizon (each 5 minutes)
    - To make time frames of 60 minutes
- Set $T1\ patients\ with\ politrauma\ or\ neurological\ injuries\ T0P = \{i: E_i = 0\}$

- Set $T1\ patients\ T1P = \{i: E_i = 1\}$
- Set $T2\ patients\ T2P = \{i: E_i = 2\}$

5.2 Data used for the input parameters

In Figure 6 we clarify what the sources of the parameters are.

Parameter	Source	Remarks
C_h, D_h	Handbook ETS	-
Level hospital	Handbook ETS and other confidential documents	Some hospitals did not have a level in the handbook, so other confidential documents owned by AZE are used.
B_h , F_h	Handbook ETS	Since separate capacity is not known, we assume Munster as a Level 1 hospital and Gronau as a Level 2 hospital which cannot treat both kinds of T1 patients.
K_{hv}	Ambulances: Handbook Helicopters: ETS exercise	For the helicopters, the ETS exercise data is used to make a linear fitting, since not all data is available. The input for this formula is the straight line distance.
E_i	ETS exercise	Normally the triage is T1, T2 or T3. In this model, just as in the exercises, the T3 patients are not taken into account, because they do not go to a hospital. As stated in Section 1.2 not all T1 patients must go to a Level 1 hospital, but only when a patient has a neurological injury or is polytrauma. To divide these patients from the patients who do not necessarily need to go to a Level 1 hospital, we created the triage level 0. All patients with E_i= 0 must go to a Level 1 hospital.
J_i	ETS exercise	Since previous times are not written down and are hard or impossible to calculate, the time a patient is in the ambulance or helicopter to travel to a hospital is used as an input for this model. This data is derived from the exercises.
U_z	ETS exercise	Each helicopter has a certain time when it is ready to distribute patients. This time is derived from the exercises. These values are converted to the number of helicopters available per time frame.

Figure 6: Sources of the parameters

In this model, the ambulances do not have a time when they are ready. We tried to implement this, but not enough information is known and assumptions are inadequate or incorrect. First of all, it is not known at what time a patient is ready for transport, only the time when he/she is assigned to an ambulance is known. Second, in the kind of model we made, it is not possible to implement waiting times or let ambulances return. For the returning of ambulances, assumptions can be made how much time it on average takes to let an ambulance return. However, since this depends on the destination of the ambulances and the time it takes differs much between the destinations this assumption is never counts for all ambulances and destinations. Moreover, estimating the average of how long it takes to return is hard: making it too short does not reflect reality, but making it more realistic (or even long), is also not possible. In that last case, ambulances are not at the stage when a patient wants to go, and since there is no waiting time, the model finds no solution. To be sure ambulances are available when a patient is assigned, we assume that an ambulance is available at the same time that ambulance was ready during the exercises.

We assume that a hospital can handle one helicopter per hour, because it takes time to empty the helicopter deck. In consultation with AZE, it is also assumed that all hospitals can receive a helicopter. Not all hospitals have a helicopter deck, but –in case of a mass causality accident- it is possible to receive a helicopter.

5.3 Decision variable

The model decides for each patient to which hospital he/she goes and with which kind of vehicle.

$$x_{hvi} = \begin{cases} 1, if\ patient\ i\ goes\ to\ hospital\ department\ h\ with\ vehicle\ v \\ 0, otherwise \end{cases}$$

For $h = 1, 2, 3, \dots, 64$; $i = 1, 2, 3, \dots, 102$ and $v = 1, 2$

5.4 Objective function

The aim for this model is to do what is best for the victims of the disaster. However, for T1 patients it is much more important that they arrive early in the hospital than for the T2 patients. T1 patients have always priority on T2 patients. Since T1 polytrauma or neurological patients are severely wounded, they are a little bit more important. To implement this in the model, it must be seen how big the factors in the objective function needs to be. Different values are used and implementing in the model, till the changes were small enough. After experimentation with different factors, the factors as can be seen in the formula below are determined.

$$\min z = 9 * \sum_{h=1}^{64} \sum_{v=1}^{2} \sum_{i \in T0P} ((J_i + K_{hv}) * x_{hvi})$$
$$+8 * \sum_{h=1}^{64} \sum_{v=1}^{2} \sum_{i \in T1P} ((J_i + K_{hv}) * x_{hvi})$$
$$+ \sum_{h=1}^{64} \sum_{v=1}^{2} \sum_{i \in T2P} ((J_i + K_{hv}) * x_{hvi})$$

5.5 Constraints

1. Each patient must be assigned to one hospital

$$\sum_{h=1}^{64} \sum_{v=1}^{2} x_{hvi} = 1\ \forall i$$

2. If hospital department 30 or 62 (Major accident Hospital / Calamiteitenhospital) has patients, then do not assign patients to hospital department 24 and 56 (Utrecht UMC)

$$M * (1 - A) \geq \sum_{i=1}^{102} \sum_{v=1}^{2} (x_{24vi} + x_{56vi})$$
$$M * A \geq \sum_{i=1}^{102} \sum_{v=1}^{2} (x_{30vi} + x_{62vi})$$
$$A = \begin{cases} 1\ (Major\ accident\ Hospital\ has\ patients) \\ 0\ (Major\ accident\ Hospital\ has\ no\ patients) \end{cases}$$

M = 999

The Major accident Hospital has two departments: a T1 and a T2 department. As soon as one of, or both the departments is/are open, $\sum_{i=1}^{102} \sum_{v=1}^{78} (x_{30vi} + x_{62vi})$ becomes 1 or 2. This forces A to be 1. If

A is one, the second line forces $\sum_{i=1}^{102}\sum_{v=1}^{78}(x_{24vi} + x_{56vi})$ to be equal to or less than 0. Since this cannot be a negative number, it must be 0.

3. If hospital department 30 or 62 (Major accident Hospital / Calamiteitenhospital) is not zero, there must be more than 5 patients

$$5 - \sum_{i=1}^{102}\sum_{v=1}^{2}(x_{30vi} + x_{62vi}) \leq M * (1 - A)$$

If the Major accident Hospital is open, at least 5 patients must come. In constraint 2 states that if the Major accident Hospital is open, than A is 1. In that case, constraint 3 states that $\sum_{i=1}^{102}\sum_{v=1}^{78}(x_{30vi} + x_{62vi})$ must be 5 or more. When A is equal to 0, $\sum_{i=1}^{102}\sum_{v=1}^{78}(x_{30vi} + x_{62vi})$ can be everything, but then the first constraint from constraints 2 states that is must be 0.

4. Capacity of Dutch T1 departments cannot be exceeded

$$\sum_{i \in S_z}\sum_{v=1}^{2} x_{hvi} \leq C_h \; for \; 1 \leq h \leq 30 \; and \; \forall z$$

The Dutch hospitals have a rolling horizon capacity. The left-hand side of this formula counts all T1 patients that are assigned in time frame S_z with any vehicle to a certain hospital. This constraints counts only for the first 30 hospitals, because that are the Dutch T1 departments.

5. Capacity of Dutch hospital (for all patients) cannot be exceeded

$$\sum_{i \in S_z}\sum_{v=1}^{2}(x_{hvi} + x_{(h+32)vi}) \leq D_h \; for \; 1 \leq h \leq 30 \; and \; \forall z$$

Since the capacity is stated as T1-capacity and Total capacity, these formula sums up all the patients in a hospital for both departments during a certain time frame.

6. T1 patients with neurological injuries or polytrauma must go to a level 1 hospital

$$E_i + \sum_{v=1}^{2}\sum_{h \in L1H} x_{hvi} \geq 1 \; \forall i$$

If a patients has a triage label 0, then it must go to a Level 1 hospital in a T1 department. This formula makes sure this happens.

7. T1 patients must be counted as T1 patient

$$E_i + 2\sum_{h=1}^{32}\sum_{v=1}^{2} x_{hvi} \geq 2 \; \forall i$$

If a patient has a triage label T1, than it must go to a T1 department.

8. Capacity German Hospitals

$$\sum_{i=1}^{102}\sum_{v=1}^{2}(x_{31vi}+x_{63vi}) \leq F_{63}$$
$$\sum_{i=1}^{102}\sum_{v=1}^{2}(x_{32vi}+x_{64vi)} \leq F_{64}$$
$$\sum_{i=1}^{102}\sum_{v=1}^{2} x_{31vi} \leq B_{63}$$
$$\sum_{i=1}^{102}\sum_{v=1}^{2} x_{32vi} \leq B_{64}$$

Since the German hospitals count with one capacity for the whole exercise per department, this formulas sum all patients.

9. Capacity Helicopter at hospital

$$\sum_{i \in S_z}(x_{h2i}+x_{(h+32)2i}) \leq 1 \; for \; h = 1,2,3,\dots,32 \; and \; \forall z$$

As stated in Section 5.1.3, each hospital can take a maximum of 1 helicopter per hour.

10. Capacity Helicopter

$$\sum_{i \in R_z}\sum_{h=1}^{64} x_{h2i} \leq U_z \; for \; \forall z$$

This formula takes the availability of the helicopters into account.

11. All decision variables are 0 or 1

$$x_{hvi} = 0 \; or \; 1 \; \forall h, \forall v \; and \; \forall i$$

The model is implemented in Excel with Coin-or. A manual how to handle this document can be found in Appendix 6.

5.6 Key performance indicators

Section 2.5 contains the key performance indicators (KPI's) of the ETS exercises, but to compare the mathematical solutions, we use slightly different KPI's. The KPI's we look at are the number of hospitals used, the sum of all times when patients arrive in a hospital, the average times when a patient with a certain triage arrives at a hospital and the time when the last patient with a certain triage arrives in a hospital. Especially the KPI 'Average time when a patients with a certain triage arrives at a hospital' is added in this model, because if we only look at when the last patient arrives, it is –theoretically- possible that all other patients arrive one minute earlier. An average is a better indicator.

5.7 Solution

Using the values given in Appendix 3 to 5, the solution is generated. This solution, which we call Scenario I, can be found in Appendix 6. Comparing these results to the results of the exercise, it can be stated that for all triage levels the average arrival time in the hospital can be shorted by 8 minutes. In total, the number of hospitals used is reduced by 4. Especially, no patient is assigned to the Major Accident Hospital in Utrecht. In total the patients travel 840 minutes less, what is equal to 14 hours. The weighted Time in Hospital is reduced by 4,505. Last, the last neurological/polytrauma T1 and the last T1 patient arrive 40 and 39 minutes earlier respectively, while the last T2 patient is still 8 minutes earlier.

5.8 Other scenarios

Besides the scenario that stimulates the ETS exercise it is also interesting what happens when some of the input values are different. That is why we come up with 5 more scenarios and their solutions in this section.

5.8.1 The scenarios

Scenario II to Scenario IV are about the helicopters. Scenario V is about the patients and the last scenario is about the hospitals. An overview of the scenarios can be found in Figure 7.

Scenario	Subject	Results
I	Mathematical solution with –as much as possible- the same values as in the exercise	Appendix 8
II	The helicopters cannot be used.	Appendix 9
III	One extra helicopter is available	Appendix 10
IV	The helicopters are only allowed to go to the hospital they are stationed	Appendix 11
V	All T1 patients must go to a Level 1 hospital	Appendix 12
VI	The hospital in Almelo is not available	Appendix 13

Figure 7: Scenarios

In Scenario I we assume that the helicopters can fly, but, as said in Section 3.2.3 only under certain weather conditions a helicopter can fly. It is also possible that the helicopter staff need to be at the disaster scene and cannot distribute patients. That are the reasons why Scenario II is devised. In this scenario no helicopter is available to distribute patients.

Figure 8 shows the reach of the LifeLiners with circles of 50 and 70 kilometres. In Twente (the region where the fictional disaster of the exercises took place), also one trauma helicopter of Germany is used: the Christoph Europa 2. As can be seen in this figure, not whole the Netherlands is covered by this circles. To solve this, an extra helicopter could be bought. In Scenario III we look ahead and see what happens if an extra helicopter is bought. It is assumed that this helicopter is ready to transport patients at the same time as the helicopter from Nijmegen.

Normally, helicopters only fly to the hospital where they come from. However, in a disaster they make exceptions and can be creative to find a place to land. In Scenario IV we investigate the importance of these exceptions.

Scenario V is found, because except in capacity of the hospitals and in the decision variable there is no difference between a T1 and a T2 patient. In addition, in the first days of this research Acute Zorg Euregio told us that all T1 patients must go to a Level 1 hospital and even though this changed, we are curious what happens when this rule is reality.

In theory, a disaster can have such a big impact that the closest hospital is not able to receive new patients. Maybe because the way to the hospital is passable, the hospital is destroyed or due to a previous disaster, there is no capacity left. Even though this is not the case in the scenario of the ETS exercise, we want to investigate how the KPI's perform if the closest hospital, in this case Almelo, is not available.

A scenario with the original triage as set by the ETS developers would be an interesting scenario. However, this is not possible at this moment, because the triage differs too much and important input data is not available and cannot be calculated. In the exercise, some patients are triaged at T1 or T2, while according to the ETS developers, they have a T3 triage and do not have to be assigned to a hospital. But also the other way around, some people were triaged as T3 in the exercise, while according to the ETS developers, they have a T1 or T2 triage. Both situations make it impossible to conduct this scenario, because the T3 patients are not included at all in the allocation of patients to hospitals and are not included in the data from the ETS exercise. Another reason why it is impossible to conduct this scenario is because patients with a lower triage (T1) are assigned before the less severely injured people (T2). Changing the triage means that the more severely injured people are not assigned first. Of course, for each of these problems assumptions can be made, but that makes the solutions of this scenario unrealistic and not suitable to compare.

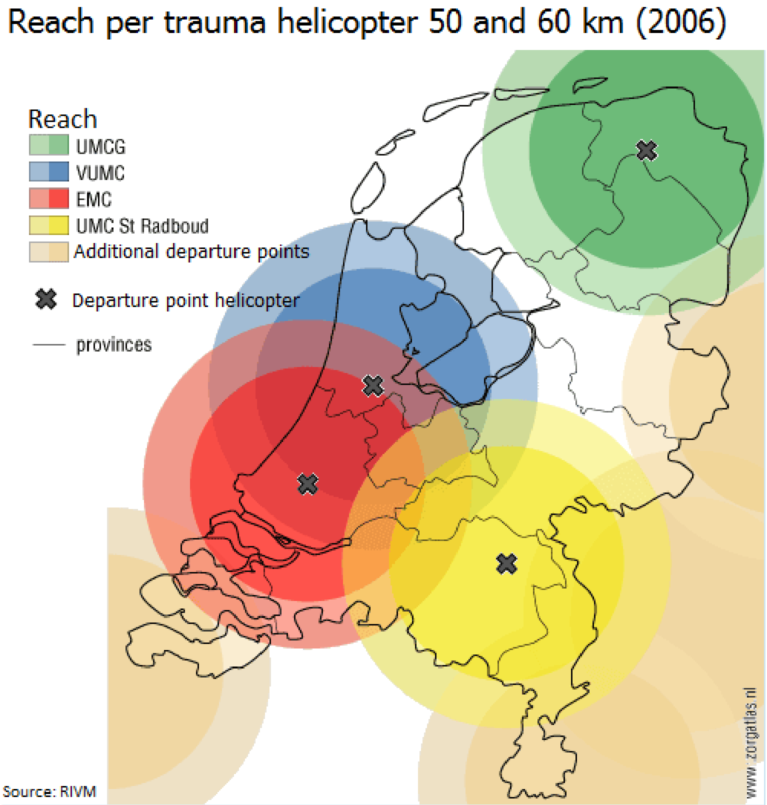

Figure 8: Reach of LifeLiners

5.8.2 Solution of the scenarios

The same model is run with the input values of the scenarios of Figure 7. The results are presented in Appendix 9 to 13 and a comparison can be found in Appendix 7. Appendix 7A contains a table with all the times per scenarios. Appendix 7B gives the difference in time compared for each scenario with Scenario I. Appendix 7C gives an overview of the number of hospitals and helicopters used in each scenario. Last, Appendix 7D gives an overview of the total number of patients per hospital in each scenario.

In Scenario II, the helicopters are not used at all. The usage of hospitals is not really different: the hospital in Apeldoorn gets one patient of the hospital in Gronau, which makes Gronau no longer involved in this disaster. In addition one T1 patient goes to Apeldoorn instead of Winterswijk. On average, it takes the patients 1.3 minutes longer to reach a hospital, for severely injured people a little bit longer than for less severely injured people. This is the same for the parameter 'Last arrives in Hospital': this only effects severely injured people. Not using the helicopters cause the 102 patients to travel 133 minutes longer in total.

Scenario III takes a look at what happens when there is one extra helicopter stationed close and used during the allocation. Compared with Scenario I, this has little effect on the variables. In total, it saves 27 minutes travel time for the patients.

Allowing the helicopters only to fly on the hospitals where the helicopters come from, makes the helicopters less used. First, helicopters were used maximal, but now, in Scenario IV, only two helicopters are used. They fly to Enschede and Nijmegen Radboud. In total it makes the patients travel 96 minutes more than using all hospitals.

In Scenario V, all T1 patients need to go to a Level 1 hospital and not only the ones with neurological injuries or polytrauma. This has a big effect on all parameters. Compared to Scenario I, the mathematical solution, an average patient needs to travel 6.1 minutes longer and also the time the last T1 patient arrives is more than half an hour later.

When the hospital in Almelo is not available, the hospitals in Zwolle and Apeldoorn are the main hospitals that take in more patients. This mainly affects the last T1 patients; this patient arrives 11 minutes later than in scenario I. In addition, it also effects the sum of times in hospital. In total, the patients travel 2.8 hours longer. However, this is scenario is still an improvement compared to the solution of 2016 for almost all patients.

5.9 Conclusion

In this chapter we build the model to allocate patients to a hospital in case of a disaster with as aim to assign the patients in a better way to a hospital. After implementing this model to Excel and Coin-or a solution was found which performed better on all KPI's. In addition, more scenarios were made and implemented to improve the allocation and to see what happens when some values were different. Some of the scenarios performed little or much better on the KPI's, such as an extra helicopter, while other scenarios performed little or much worse on the KPI's, such as not using Almelo.

6. Conclusion and recommendations

This chapter contains the conclusions and recommendations that can be derived from this research. Conclusions about the model can be found in Section 6.1. Recommendations for the allocation of patients to hospitals and helicopters in real life can be found in Section 6.2, recommendations for the ETS exercises can be found in Section 6.3 and lastly, for further research is presented in Section 6.4.

6.1 The model

First of all, the model does what it is supposed to do in less than two minutes. The model decides for each patient to what hospital he/she must go and with what kind of vehicle. The times when the patients arrive in the hospital are calculated and conclusions are made.

The model has great positive impact on the patients' well-being, but also the number of hospitals used is less than during the ETS exercise. In total the sum of the time when the patients arrive at a hospital can be reduced by 14 hours.

6.2 In real life

This model allocates patients to hospitals. Besides a mathematical solution of the exercise, also different scenarios are implemented. Based on the results of these different scenarios, the following recommendations are made.

Helicopters do not make a great difference on the times. Since the personnel of helicopters can do treatments ambulance personnel cannot do, the helicopter personnel is probably more useful at the disaster scene. Besides, it is not beneficial for the patients to be taken to the hospital where the helicopter is stationed. Patients can get treatment sooner when they go to another hospital.

The Major accident Hospital is far away from the disaster scene in this scenario. Hospitals close by might be better for the patients than the Major accident Hospital. So the advice is to start using the Major accident Hospital only if there are a lot of T1 patients with polytrauma or neurological injuries.

More T1 patients cause a lot more patients to wait longer. Since there is a great difference between the exercises of 2015 and 2016 in the number of T1 patients, while it should be kind of the same according to the ETS developers, we advise to train the ambulance personnel to do triage well. In that case, no patient has to wait longer than necessary or is later in the hospital because their triage was lower than he/she had to get.

Last, if a hospital is not available, the hospitals nearby are still able to handle all the patients. It all takes a little bit longer, but it is still manageable.

6.3 ETS exercises

A lot of information of the ETS exercises is used for this model. To improve this model, more information needs to be derived from the exercises. Therefore, when AZE decides to do more ETS exercises we advise the following adjustments.

First of all, we advise to use the exact same scenario as the previous exercise. Any comparison can be made best, if the starting point is equal. This means, same patients (in case of triage and injuries), same number of vehicles and same capacities, instead of making a new starting point every exercise.

Second, we advise to note down more information. First, we advise to note down the numbers of the patients who are in the dangerous zone and need to be freed by the fire brigade, so when another exercise is held, the same patients can be put there and a new model can take this into account. Secondly, a great improvement can be made if it is known when a patient is ready to be assigned to an ambulance or helicopter. The information of the ETS exercise now only contains the times when the patient is assigned to a vehicle. Third, to make a new model, it would be better if the capacity of the German hospitals is known per hospital and not in total. Fourth, it would be nice if it is written down at what time the exercise starts.

Third, we advise to reconsider the role of the ETS leader. To make the exercises comparable it is important that the ETS leader does not make changes during the exercises. We advise that the role of the leader is to check whether everything goes according to the rules of the exercise and to answer questions if anything is unclear for the participants.

Last, in the exercises already held by AZE, the triage was a part of the exercise. This made the exercises of 2015 and 2016 hard to compare with each other looking at allocation. If AZE wants to compare a new exercise with a mathematical model, looking at the assignment of patients to vehicles and hospitals, we advise them to exclude the triage from the exercises and use fixed triage levels. If the same triage is used, the assignment of patients to hospitals can be compared easier.

6.4 Further patient to hospital modelling

When new information of the variables stated in Section 6.3 is obtained, this can be used to upgrade this model. In that case also the extra scenario can be implemented with the original triage of the ETS developers. Besides there are two more options to improve the allocation of patients to hospitals.

The first possibility is to make a model that includes the waiting times and the re-use of ambulances and helicopters. Due to time constraints, it was not possible to implement this during this project. A job shop scheduling with multiple machines is suggested for modelling with waiting times[20].

The second probability for further research is making a model where patients are assigned one by one. Doing that in this model will assign the first patients to the closest hospitals and then ever further. This new model has to have ‘a pass-rate’ based on the number of patients that are already assigned and the estimation of patients who still need to be assigned. This pass-rate indicates if an ambulance or helicopter can fly to the closest hospital or has to travel to the second, third or more closest hospital. The suggestions above help the research to make the patient allocation as efficient as possible.

References

1. Landelijk Netwerk Acute Zorg. (n.d.). *Samenwerking is van levensbelang.* Retrieved March 27, 2017, from http://www.lnaz.nl/acute-zorg

2. Acute Zorg Euregio. (n.d.). *Onze opdracht.* Retrieved March 30, 2017, from http://www.acutezorgeuregio.nl/nl/acute-zorg-euregio/doel-acute-zorg

3. Emergo Train Systems. (2007). *Welcome to Emergo Train Systems.* Retrieved March 27, 2017, from http://www.emergotrain.com

4. Triage. (n.d.) Mosby's Medical Dictionary, 8th edition. (2009). Retrieved April 6, 2017, from http://medical-dictionary.thefreedictionary.com/triage

5. Landelijk netwerk acute zorg. (n.d.) Criteria voor levelindeling ziekenhuizen. Retrieved May 15, 2017, from http://www.lnaz.nl/trauma/levelcriteria

6. neurology. (n.d.) Dorland's Medical Dictionary for Health Consumers. (2007). Retrieved July 25, 2017, from http://medical-dictionary.thefreedictionary.com/neurology

7. polytrauma. (n.d.) Dorland's Medical Dictionary for Health Consumers. (2007). Retrieved July 25, 2017, from http://medical-dictionary.thefreedictionary.com/polytrauma

8. Aboueljinane, L., Sahin, E., & Jemai, Z. (2013). *A review on simulation models applied to emergency medical service operations*. Computers & Industrial Engineering, 66(4), 734-750.

9. Wallace, D. J., Kahn, J. M., Angus, D. C., Martin-Gill, C., Callaway, C. W., Rea, T. D., ... & Seymour, C. W. (2014). *Accuracy of prehospital transport time estimation.* Academic Emergency Medicine, 21(1), 9-16.

10. Ho, J., & Casey, B. (1998). *Time saved with use of emergency warning lights and sirens during response to requests for emergency medical aid in an urban environment.* Annals of emergency medicine, 32(5), 585-588.

11. O'Brien, D. J., Price, T. G., & Adams, P. (1999). *The effectiveness of lights and siren use during ambulance transport by paramedics.* Prehospital Emergency Care, 3(2), 127-130.

12. Ambulancezorg Nederland. (2016). *Landelijk protocol ambulancezorg 8.1.* Zwolle: Ambulancezorg Nederland.

13. Dantzig, G. (2016). *Linear programming and extensions*. Princeton university press.

14. Winston, W. L., & Goldberg, J. B. (2004). *Operations research: applications and algorithms* (Vol. 3). Belmont: Thomson Brooks/Cole.

15. Wilson, D. T., Hawe, G. I., Coates, G., & Crouch, R. S. (2013, January). *Effective allocation of casualties to hospitals in mass casualty incidents.* In Conference Anthology, IEEE (pp. 1-4). IEEE.

16. Carr, B. G., Walsh, L., Williams, J. C., Pryor, J. P., & Branas, C. C. (2016). *A geographic simulation model for the treatment of trauma patients in disasters*. Prehospital and disaster medicine, 31(04), 413-421.

17. Wilson, D. T., Hawe, G. I., Coates, G., & Crouch, R. S. (2013). *A multi-objective combinatorial model of casualty processing in major incident response.* European Journal of Operational Research, 230(3), 643-655.

18. Amram, O., Schuurman, N., Hedley, N., & Hameed, S. M. (2012). *A web-based model to support patient-to-hospital allocation in mass casualty incidents.* Journal of Trauma and Acute Care Surgery, 72(5), 1323-1328.

19. Repoussis, P. P., Paraskevopoulos, D. C., Vazacopoulos, A., & Hupert, N. (2016). *Optimizing emergency preparedness and resource utilization in mass-casualty incidents.* European Journal of Operational Research, 255(2), 531-544.

20. Yamada, T., & Nakano, R. (1997). Job shop scheduling. *IEE control Engineering series*, 134-134.

Reference figures

Figure 1:
http://acutezorgeuregio.nl/nl/ketenpartners

Figure 2:
http://www.emergotrain.com/index.php?option=com_content&view=category&id=25&Itemid=399

Figure 4:
Confidential document of AZE

Figure 5:
Ambulancezorg Nederland. (2016). *Landelijk protocol ambulancezorg 8.1.* Zwolle: Ambulancezorg Nederland.

Figure 8:
http://www.112vallei.nl/page/Nieuwsdetail/6950/ergernis-over-verbod-nachtvluchten-traumaheli