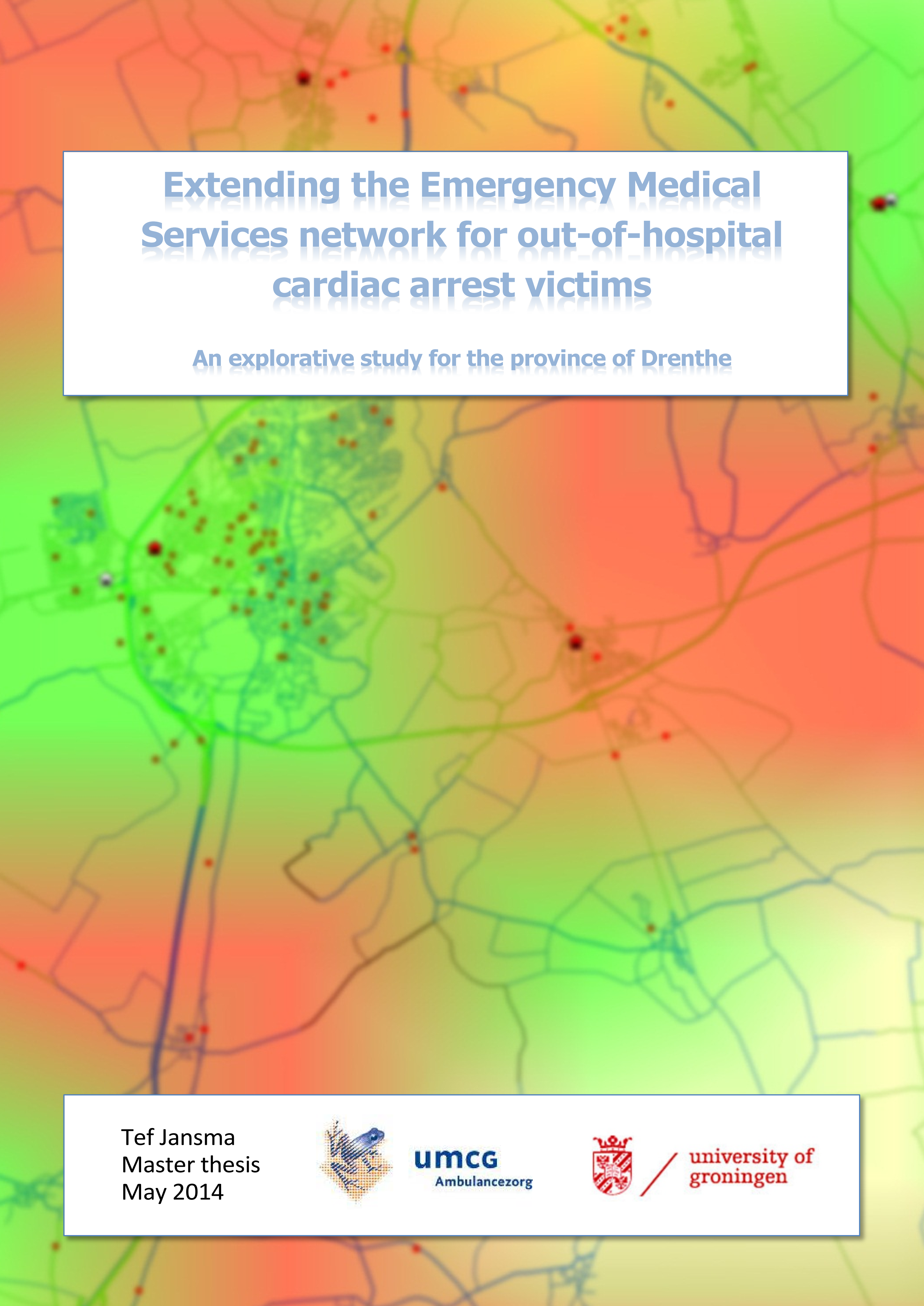

Extending the Emergency Medical Services network for out-of-hospital cardiac arrest victims

An explorative study for the province of Drenthe

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Summary

This thesis provides suggestions for a redesign for increasing the survival rates for out-of-hospital cardiac arrest (**OHCA**) victims in the province of Drenthe. An OHCA is cessation of cardiac mechanical activity that is confirmed by the absence of signs of circulation and occurs outside a hospital setting. One out of thousand people each year have an OHCA, so the region of Drenthe has to cope with about 500 victims each year.

The traditional treatment of an OHCA is to have a bystander call the emergency number 112 and wait for an ambulance from an Emergency Medical Services (**EMS**) provider to arrive. Unfortunately, the EMS provider often arrives too late to provide adequate care. This is partly because the EMS network is primarily optimized to meet the legal requirements: these only prescribe that any EMS provider needs to arrive within fifteen minutes in 95% of the high-priority calls. However, effective OHCA treatment consists of specific sequence of steps, which have much tighter time requirements.

These consecutive steps are called 'The Chain of Survival', and consist of timely recognition, cardiopulmonary resuscitation (**CPR**), defibrillation, and advanced cardiac care. Quicker execution of these steps will directly increase the survival probability. Currently, the estimated survival probability for this region in an EMS-only treatment strategy is estimated to be about 11%. However, some known examples of civilized Western countries manage to achieve survival rates up to 25%. Hence, the research objective for this thesis is:

… to deliver a cost-efficient system redesign for UMCG Ambulancezorg that improves the estimated survival rate for out-of-hospital cardiac arrests to 25%.

The quantitative data that was used in this thesis was:

- EMS call data; from the control center Meldkamer Noord-Nederland (**MKNN**) and UMCG Ambulancezorg.
- Volunteer alert data; from the MKNN .
- Average vehicle speed data per road link from ambulances; delivered by CityGIS.
- Location data of registered volunteers and automated external defibrillators (**AED**); from the HartslagNu platform

Qualitative data was extracted through interviews with people from the MKNN, UMCG Ambulancezorg and Hartslag voor Nederland.

This thesis was executed by an Industrial Engineering & Management student and therefore the suggestions for the redesign are limited to a socio-technical system. The analysis and redesign suggestions are based on calculations from spreadsheet software and two simulation software packages. One of these simulation software packages is Optima Predict, which is a dedicated geographical information system simulation package for EMS providers.

The results show that it is impossible to strive for an EMS-only solution to attain the desired estimated survival rate of 25%. Even the addition of three new posts, located according to a call hotspot strategy, will only increase the survival rate with 1%. This does not justify the annual costs of 2 million euro that comes with such a solution. Other possible changes, which include other post positions, alternative vehicle strategies, and different dispatch logic, also have no significant positive impact in survival rates.

Hence, UMCG Ambulancezorg needs to rely on supplementary networks. Four networks have been considered: those of the firefighters, police, volunteers and publicly placed AEDs. If multiple networks cooperate appropriately, results indicate that attaining a survival rate 25% should be possible for the region of Drenthe.

On a region-wide level, active engagement of the firefighters and police network shows promising results, in which the overall survival rates increase to 18.6%. If 150 vehicles from the firefighters and police region-wide would be equipped with an AED, which translates to three equipped vehicles per post, the investment cost would be 225.000 euros. The annual costs, primarily for maintaining defibrillation procedure knowledge, would be 30.000 euros.

Of the considered networks, CPR is best provided by the volunteer network, since this is the only network effectively able to arrive within 4 minutes relatively often. This network could also be very well used for defibrillating the victims, given that advanced care arrives shortly thereafter. Simulations for an urban area show that a volunteer-only response supported by AEDs gives survival rates of 17.1% - 25.8%. These numbers assume that the volunteers put effort in traveling quickly (16 km/h - bike speed) and that the number of publicly available AEDs is doubled; in the simulated case this means that there is nearly 1 AED per square kilometer. Such a doubling of AEDs for the region of Drenthe means the installment of 230 new AEDs and costs about 345.000 euros, with negligible annual costs.

Expanding the volunteer and AED base is essential to increase the probability of a successful response. Also, more data needs to be collected in the future about the performance to allow more data-driven decision-making. This applies specifically for the volunteer alerting platform.

Foreword & Acknowledgements

There is an incoming sound of sirens. Just moments later, you can see the flashing lights. Next, a yellow vehicle is passing you with high velocity. And it disappears just as quickly as it showed up.

The world of ambulances is one that is rather invisible for most of us. Yet, we all know how important they are when medical care is quickly needed. In the Netherlands, ambulances are operated by Emergency Medical Services providers and their goal is to provide adequate and timely care and transport. One of them, UMCG Ambulancezorg, wishes to know what they could do to increase the survival probability of victims having an out-of-hospital cardiac arrest. The results show that it is definitely possible to improve the timeliness, although the way in which this could be achieved, may be surprising to some.

This thesis would never have been possible without the aid of my supervisors. Therefore, I would like to thank my University of Groningen supervisors dr. ir. Durk-Jouke van der Zee and dr. ir. Wilfred H. M. Alsem for their guidance, discussions and feedback. The same applies to my company supervisor ir. Jaap Hatenboer, the vice president of UMCG Ambulancezorg. His enthusiasm and innovative mindset was inspiring and motivated me throughout my research. As a student with a non-medical background, I would also like to thank Harriëtte Holt and Hessel Jonker for their time to make me familiar with the terminology and procedures in the world of an Emergency Medical Services provider. Also, I would like to thank all those who have cooperated in interviews and tours, and provided me with valuable information in person, by phone or in some digital form: Jacques Besseling, Rob van Meer, Christina Westerbeek, Myrthe Mos, Marco Janssen, Ron Gerrits, Theo Schrijnemaekers, Ruud Pijls, employees at UMCG Ambulancezorg, MKNN call takers and dispatchers, Optima Predict support, and all other individuals that helped me in one way or another. Last but not least, I would like to thank my girlfriend, friends, and family that supported me whenever I experienced a setback.

Contents

Glossary

A1 call: a call from any person to the control center that is being classified as very urgent. These calls are the highest priority calls and law dictates that any emergency medical services provider is at the scene within 15 minutes in 95% of the cases.

A2 call: a call from any person to the control center that is being classified as medium priority. The law dictates that any emergency medical services provider is at the scene within 30 minutes in 95% of the cases.

B call: a call that is classified as non-urgent or pre-scheduled transportation.

Response time: the time between the start of the call at the control center and the arrival of the first vehicle at the scene. Hence, the response time is the sum of the call time at the control center, the mobilization time at the ambulance post, and the actual driving time to the scene.

Call time: the time it takes at the control center to accept an incoming call, make a diagnosis and dispatch the appropriate vehicle.

Mobilization time: the time it takes for a dispatched crew to get to their vehicle and start driving to a scene.

Cardiopulmonary resuscitation: the act of applying compressions to the chest, with the intention of stimulating blood flow. It may or may not be guided with breaths.

Defibrillation: the act of defibrillating a person. This is done through a defibrillator, which is a device that generates an electrical shock. In some cases, this electrical shock will cause the heart to start beating again.

Automated External Defibrillator: these are user-friendly defibrillators. It often has automated spoken instructions, and will automatically defibrillate a victim if the device finds the appropriate heart rhythm.

Advanced (Cardiac) Care / Advanced Life Support: refers to highly advanced medical tools and expertise.

Primary Network: as this thesis is initiated from the perspective of an EMS provider, this network refers to the mix of posts, vehicles and staff of an EMS provider.

Supplementary networks: the mix of posts, vehicles and staff for other networks than the primary network. The networks considered in this thesis are those of the firefighters, police, volunteers and automatic external defibrillators.

Abbreviations

A1	High priority calls
A2	Medium priority calls
AED	Automatic External Defibrillator
ALS	Advanced Life Support
B	Low priority calls or planned transportation.
BLS	Basic Life Support
CPR	Cardiopulmonary Resuscitation
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
FIFO	First In, First Out
GIS	Geographic Information System
GMS	Geïntegreerd Meldkamer Systeem (integrated control center system)
GPS	Global Positioning System
HEMA	Hoogeveen, Emmen, Meppel, Assen
IV	Inzetvoorstel (dispatch proposal)
MKNN	Meldkamer Noord Nederland (control center of the North Netherlands)
MMT	Mobiel Medisch Team (mobile medical team)
OHCA	Out-of-Hospital Cardiac Arrest
OR	Odds Ratio
PEA	Pulseless Electrical Acitvity
pVT	Pulseless Ventricular Tachycardia
RAV	Regionale Ambulance Voorziening (regional ambulance facility)
ROSC	Return Of Spontaneous Circulation
UMCG	University Medical Center Groningen
VF	Ventricular Fibrillation

1. Introduction

1.1 Topic

This thesis is concerned about increasing the survival rates for out-of-hospital cardiac arrests (**OHCA**) in the region of Drenthe. An OHCA is cessation of cardiac mechanical activity that is confirmed by the absence of signs of circulation and that occurs outside of a hospital setting. A better responsiveness for OHCA victims is highly related to their survival probability.

1.2 Company description

The problem owner of this thesis is UMCG Ambulancezorg, one of the Emergency Medical Services (**EMS**) providers in the Netherlands. UMCG Ambulancezorg provides services in the provinces of Drenthe and a part of Friesland. The section that delivers services in Friesland is called Ambulancezorg Fryslân and is owned $^2/_3$ by UMCG Ambulancezorg and $^1/_3$ by Antonius hospital Sneek/Emmeloord.

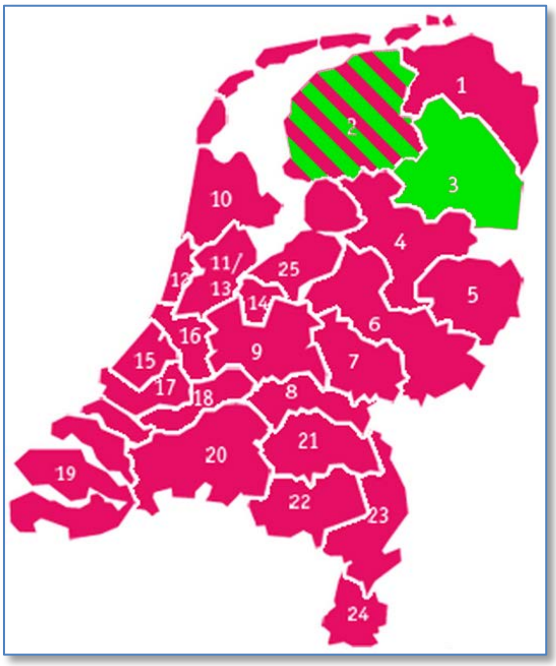

Figure 1: the twenty-five safety regions of the Netherlands. UMCG Ambulancezorg operates in the green regions.

The main principle of UMCG Ambulancezorg is to provide 'responsible care'. Its goal is to make patients feel that they are in trusted hands and that everybody can rely on them, in situations where every second counts. The mission of UMCG Ambulancezorg is to be an involved and entrepreneurial provider of sound ambulance care in the provinces of Drenthe and Friesland. UMCG Ambulancezorg delivers services based on the following principles:

- The care delivered must meet the needs of the care recipient as much as possible.
- The care delivered must contribute as much as possible to the quality of life of the care recipient.
- Health is a shared responsibility of the patient and the care provider.
- The available budget is transformed into care as efficient as possible.

The network of UMCG Ambulancezorg consists of 14 ambulance posts in Drenthe[1]. There are also 7 posts in Friesland, operating under the name of Ambulancezorg Fryslân. Friesland also has another EMS provider, Kijlstra, which has 10 posts in Friesland. There are an additional 2 posts in Friesland which are shared by both the EMS providers. Together, UMCG Ambulancezorg and Kijlstra cover the full provinces of Drenthe and Friesland, with several dozens of ambulances[2]. The ambulances need to serve about 70.000 calls each year[3]. These include emergency calls and planned transportation. About 230 people are working at UMCG Ambulancezorg, of which roughly 75% work on the ambulances. The remainder is working at the control center or is in a human resource or management employment. The employees together hold about 210 full time employments.

1.3 Structure of thesis

This thesis is structured in the following fashion: **Chapter 1** (*Introduction*), which is this section, has given a topic introduction and a brief introduction of the company.

The following section, **Chapter 2** (*Research Design*), elaborates on the identified problem and puts it into its context. It shows the assumptions, problem definition and research approach for the remainder of this thesis. Within this chapter, the following sub-sections can be identified: the problem context, problem definition, performance indicators, conceptual model, research questions, and research plan.

Chapter 3 (*Out of hospital cardiac arrest Survival Factors*) elaborates on factors known in this field of literature that influence the survival probability of out-of-hospital cardiac arrests. This chapter will show that this type of injury has very specific medical needs, within very narrow time windows.

After that, **Chapter 4** (*Emergency Medical Services Design Parameters*) focuses on the logistical implications of Chapter 3. It shows how the survival factors from the previous chapter can be transformed into design parameters to improve the responsiveness for OHCAs.

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[1] The exact number of posts (on duty) varies over time.
[2] The exact number of ambulances on duty varies over time
[3] This excludes cancelled or preventive rides. If only calls sed in national statistics are counted, the amount of calls is about 50.000.

After that, **Chapter 5** (*Current System Design*) describes the current system of UMCG Ambulancezorg, using the relevant design parameters as identified in the previous chapter.

In **Chapter 6** (*System Analysis*), the performance of UMCG Ambulancezorg regarding out-of-hospital cardiac arrests is critically evaluated and potential points that could lead to improvement are identified.

Next up is **Chapter 7** (*System Redesign*), in which solutions are presented and tested that should lead to a better system performance. This chapter also contains a section with sensitivity analysis and looks forward for possible future scenarios.

Chapter 8, **9** and **Appendices** finish this thesis with conclusions, suggestions for further research, and background information.

2. Research design

2.1 Problem context

2.1.1 Introduction

There is a highly professionalized system of EMS providers in the Netherlands. The EMS providers historically all operate in specific safety regions. Article 4 of the temporary law Ambulance care (“tijdelijke wet Ambulancezorg,” 2013) specifies that each safety region should have one EMS provider. The safety regions are exactly the same regions as defined in article 8 of the law Safety Regions (“wet Veiligheidsregio’s,” 2013). However, as noted before, UMCG Ambulancezorg has to share its services in Friesland with a competitor, Kijlstra. This is allowed because they operate as one entity under law, as Coöperatie RAV Fryslân. Hence, the EMS provider in Friesland operates under the name of Ambulancezorg Fryslân.

2.1.2 Out-of-Hospital Cardiac Arrest (OHCA)

This thesis is concerned about increasing the responsiveness for out-of-hospital cardiac arrests (**OHCA**). An out-of-hospital cardiac arrest is cessation of cardiac mechanical activity that is confirmed by the absence of signs of circulation and that occurs outside of a hospital setting. A common misconception is that a cardiac arrest is the same as a heart attack. This is not true, since a heart attack is an impaired blood flow to the heart muscle itself.

UMCG Ambulancezorg needs to respond to different types of calls. On the highest level there is a distinction in A1, A2 and B calls. A1 calls are life threatening calls, A2 are less urgent calls and B calls are planned transportation. Since OHCAs are always life-threatening, they are always A1 calls.

2.1.3 Medical context

OHCA survival and timely medical care from EMS crew are related strongly (Persse, Key, Bradley, Miller, & Dhingra, 2003), (Vukmir, 2006), (Sund, 2013). In fact, time may be the most critical component that determines whether there is any probability of survival: the probability of survival diminishes each minute and is about zero after 12 minutes under normal circumstances. More detail about this relation between time and survival probability is explained in depth in Chapter [**3**].

Besides a timely response being essential, a sequence of specific steps need to be executed, which is also known as ‘The Chain of Survival’ (Hollenberg, Svensson, & Rosenqvist, 2013). These steps are early recognition, cardiopulmonary resuscitation (**CPR**), defibrillation, and advanced life support (**ALS**). In studies where all steps were executed immediately after a collapse, very high survival rates have been reported, in some cases near 100% (see section [**3.7**]). Ideally, CPR should be started within 4 minutes and defibrillation within 8 minutes to ensure acceptable survival probabilities without major brain damage. Executing the steps in the Chain of Survival is very labor-intensive: an average person is able to provide adequate CPR for only about two minutes. ALS also consists of very complex actions, calling for the need of at least two, but preferably three trained professionals.

2.1.4 Legal context

EMS providers are only allowed to do their work if they have a license to do so. These licenses are issued once by the minister of Public Health, Welfare and Sports (RIVM, 2010) and come with governmental performance requirements. One of these is that the A1 calls (recall that OHCAs are always A1 calls) should have the first ambulance arriving at the incident scene within 15 minutes in 95% of the times. This requirement applies to any safety region as a whole. This 15 minute limit applies to the **response time**, which is the sum of the call time at the control center, the mobilization time at the ambulance post, and the drive time to the incident scene. This is illustrated in the figure below.

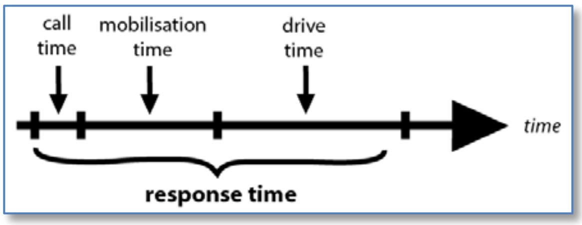

Figure 2: graphical representation of the response time.

Hence, all ambulances arriving within 15 minutes contribute positively to the A1 (response time) performance, which needs to be 95%. This is very important for UMCG Ambulancezorg, because not meeting this requirement can result in losing its license to provide EMS services.

The Dutch A1 response time requirement is not science-based (Malschaert, Belt, & Giesen, 2008). It first appeared in the ‘80s in the law ‘Wet Ambulancevervoer’ (de Nooij, 2003), without any meaningful motivation. Other countries also use response time performance requirements, but often use different thresholds. For example, the United States use a 10 / 30 minutes response time (95%) for urban / rural areas. The United Kingdom recently changed the response time requirement from 15 minutes (95%) to 8 minutes (75%) (Department of Health, 2000).

2.1.5 Relevance

Many allocation decisions within UMCG Ambulancezorg are dominated[4] by the legal response time requirement of 15 minutes. The effect of this is clearly illustrated in national statistics (Ambulancezorg Nederland, 2012): although the response time performance is steadily improving, it comes at the cost of increased average response times. The strategies seem to be focused on reducing variability for the mass of calls. This is disadvantageous for OHCAs, for which the difference between a permanent death and life is very time-dependent. Some recent studies therefore state that it would be better to differentiate more according to incident type and design strategies based on that (Erkut, Ingolfsson, & Erdogan, 2008), (Knight, Harper, & Smith, 2012).

The current survival rate of OHCAs in this region is low. Exact numbers are not available, due to poor incident type classification, data registration, and privacy concerns of hospitals. However, through manual data examination and interviews with nurses and cardiologists it is estimated to be around 10%-15% for this region. Although this is better than many rural countries, a region in a densely populated western county, such as the Netherlands should do better: survival rates as high as 25% overall, and 55% for specific subtypes are reported by some foreign EMS providers such as King County, Washington (Public Health - Seattle & King County, 2013) and Mecklenburg County, North Carolina (Medic, 2013).

2.1.6 Limitations and focus

This thesis has time limitations. Therefore, not all possible design parameters can be included, given the available time frame. The time limitations also imposed some boundaries on the type of injuries that could be considered: an overview and motivation is given in Appendix [**A**]. The focus of this thesis is the evaluation and design of a socio-technical system, because of the educational background of the author. This means that other aspects, such as those related to communication, legal, history will receive less attention.

2.2 Problem definition

The **research objective** of this thesis is:

> *… to deliver a cost-efficient system redesign for UMCG Ambulancezorg that improves the estimated survival rate for out-of-hospital cardiac arrests to 25%.*

The corresponding **research question** is:

> *How can EMS systems be modified to improve survival rates for out-of-hospital cardiac arrests?*

2.3 Performance indicators

The performance for EMS providers may be measured across eight dimensions (Meara, 2005). Two of those are the most appropriate for a socio-technical redesign (van Werven, 2012): *efficiency* and *effectiveness.* These two dimensions have the following structures, processes, and outcomes:

Dimension	Efficiency	Effectiveness
Structures	Staff to case ratios	Equipment Staff skills
Processes	Rostering systems	Response times Resuscitations Interventions
Outcomes	Affordability Cost-effectiveness	Mortality Survival

Table 1: The structures, processes and outcomes of Effectiveness and Efficiency (Meara, 2005)**.**

For efficiency, affordability is used as outcome and operationalized as investment costs (€) and variable costs (€ / year).

For effectiveness, it would be preferred to directly operationalize survival. However, as the next chapters will show, estimations for survival rates depend on a lot of complex interactions between the work of an EMS provider, external parties, and the follow-up care of hospitals. Therefore, it is chosen to also use the underlying logistical measures on which the survival estimate in this thesis is based: the amount timely initiated of cardiopulmonary resuscitation (**CPR**) within 4 minutes (%), defibrillation within 8 minutes (%) and advanced care within 12 minutes (%)[5]. Below is a summary:

The **performance indicators** are:

- Survival rate estimate (%)
    - CPR initiated within 4 minutes (%)
    - Defibrillation initiated within 8 minutes (%)
    - Advanced care initiated within 12 min. (%)
- Investment costs (€)
- Variable costs (€ / year)

The amount of timely initiated CPR and defibrillation are to be maximized, under justifiable investment costs and variable costs.

2.4 Conceptual model

The conceptual model is shown below. The core activity (middle block) is to provide prehospital care for victims of an OHCA. The input of this activity are the patient characteristics, which consists of a diagnosis of complaints, address, age, gender, etc.

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[4] Acknowledged by senior employees and the (deputy) director of UMCG Ambulancezorg.

[5] Chapter 3 explains and elaborates on these activities.

The desired output of the activity are patients that have received adequate prehospital OHCA care.

As will be shown later on, the design parameters are: post locations, vehicle decisions, staffing, control logic and effective use of supplementary networks. These parameters are the ‘knobs’ that can be used to influence the quality of the prehospital OHCA care that is provided. The performance of the activity is measured by the moment CPR, defibrillation and advanced care was given, and the fixed and variable costs.

The most important controls and resources are listed on top of the diagram. The main activity is constrained by controls, which are laws and regulations, and expectations from society. Finally, the most important resources can be identified from three sources: UMCG Ambulancezorg provides posts, vehicles and crew; the control center provides crew due to the resource dispatch decisions that they make; supplementary networks provide people and equipment to perform CPR and defibrillation. The considered supplementary networks are those of the police, firefighters, volunteers and AEDs.

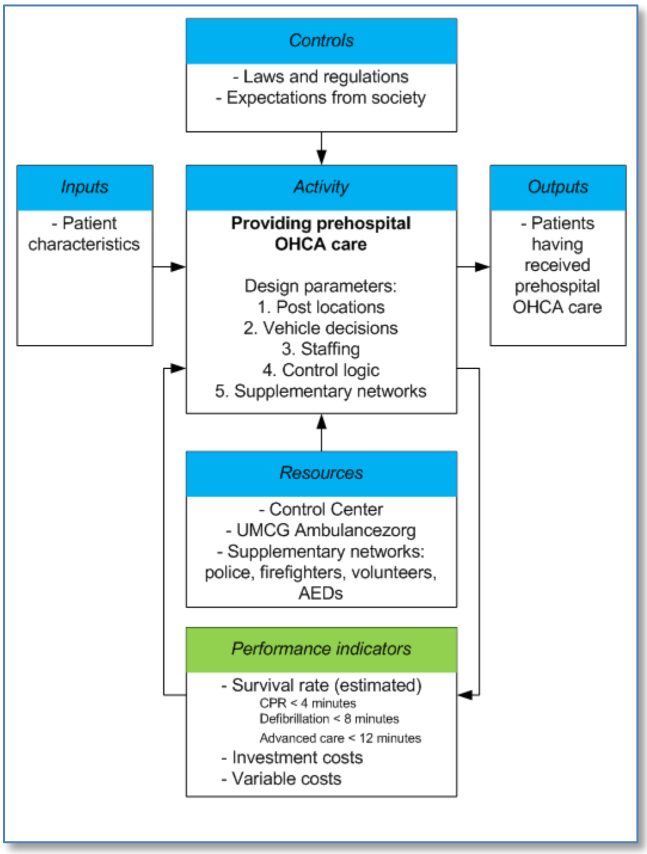

Figure 3: conceptual model, showing the activity focus, inputs, outputs, controls, resources and performance indicators.

2.5 Research questions

In order to answer the main research question and achieve the research objective, the following **sub questions** will be answered:

- Which factors influence survival of an out-of-hospital cardiac arrest?
- What are relevant design parameters for UMCG Ambulancezorg?
- What is the current system design?
- What is the current performance and how can it be explained?
- How can the system be redesigned to achieve better performance?

These five sub questions are answered in the following five chapters, respectively:

- Chapter 3 (OHCA Treatment)
- Chapter 4 (EMS Design Parameters)
- Chapter 5 (Current System Design)
- Chapter 6 (System Analysis)
- Chapter 7 (System Redesign)

2.6 Research plan

1. The first step is a literature search (Chapter 3 and 4) to systematically describe which factors contribute to the probability of surviving an out-of-hospital cardiac arrest. This section therefore elaborates on ‘medical’ issues. This is needed, because it provides a scientific basis to translate the often intangible factors into ‘hard’ logistical performance measures that can be used to redesign the system. To clearly separate between the medical and logistical approach, the literature is structured into two subsequent chapters.

2. The second step is to describe the current system design in terms of the parameters found during the literature search. This is done in Chapter 5, which will be a merely descriptive chapter, just stating the status quo without any analysis or verdict.

3. The third step is a system analysis, which is executed in Chapter 6. This chapter investigates the current system design, elaborates on its current performance and tries to find explanations for this performance. Data collection and analysis of the system will be done as follows:

- Interviews with management and employees from the Control Center, UMCG Ambulancezorg, the police, firefighters and hartslagNU.
- Observation and data analysis of data from the Control Center, UMCG Ambulancezorg and HartslagNU. Quantitative data analysis will be done in spreadsheet software.

4. In Chapter 7, the knowledge and insights from the previous steps is used to come up with a meaningful system redesign to attain better responsiveness. To test possible scenarios, simulation software is used: Plant Simulation for rudimentary tests, and Optima Predict to represent the actual geograhpical region of Drenthe.

5. The last step is finalization. This includes an evaluation, conclusions and recommendations in Chapters 8 and 9.

3. Out-of-Hospital Cardiac Arrest Treatment

3.1 Introduction

3.1.1 Literature search approach

This chapter will elaborate on the present state of factors known to increase the survival probability of an out-of-hospital cardiac arrest (**OHCA**). The literature search was done through the search engines Google Scholar, PubMed, Web of Science, and Emergency Medicine. First, reviews and meta-analyses were identified and their references were used to explore further. The initial reviews were (Sasson, Rogers, Dahl, & Kellermann, 2010), (Hüpfl, Selig, & Nagele, 2010), (Kroll et al., 2012), and (Hollenberg et al., 2013). The used search phrases were combinations of {review, meta, cardiac arrest, OHCA, survival probability, EMS, response time, CPR, bystander, defibrillation, AED, heart rhythm}. After filtering for relevance and usability, this literature search resulted in 47 relevant papers.

3.1.2 General definitions

An out-of-hospital cardiac arrest (**OHCA**) is cessation of cardiac mechanical activity that is confirmed by the absence of signs of circulation and that occurs outside of a hospital setting (Roger & Lloyd-Jones, 2011), (Jacobs, NadKarni, & Bahr, 2004). A common misconception is that a cardiac arrest is the same as a heart attack. This is not true, since a heart attack is an impaired blood flow to the heart muscle itself.

There are many definitions for **survival** within this field of literature. Much used survival terms are survival upon hospital admission, hospital discharge, 1-month survival, 1-year survival and 5-year survival. The measure that is most used for OHCAs is the hospital discharge survival rate. Therefore, survival in this thesis always refers to survival upon hospital discharge, unless stated otherwise.

The phrase **baseline survival (rate)** refers to the average survival probability within a specified region under regular circumstances. For example, if study X concludes that the average survival probability in region A is higher than that of region B, one could say: study X has found that region A has a higher baseline survival.

The **odds ratio** (**OR**) is the proportion between two odds. It is therefore often interpreted as the 'relative risk'. For example: consider a group of 100 men and 100 women, in which 40 of the men develop a headache, and 80 of the women. Women are 80/40 = 2 times more likely to develop a headache, but have 6 times the odds, as the OR is (80/20) / (40/60) = 6.

3.1.3 Causes for OHCAs

The underlying reasons for OHCAs are diverse and include: coronary artery disease, heart attack, cardiovascular disease, diabetes, obesity, smoking, high cholesterol, hypertension and recreational drug use. OHCAs may occur without a specific event, or may be provoked by drowning, electrocution, respiratory arrest, choking, or trauma. Prevention is partially possible through regular exercise, having a healthy weight, and eating a heart-healthy, low-salt diet. Although OHCAs seem to be random events, this is not true, because most of the victims have a heart disease or disorder, while not being aware of it (Fishman et al., 2010).

3.1.4 Structure of this chapter

This chapter is structured as follows. Section 3.2 introduces the Chain of Survival concept, which serves as framework for the remainder of this chapter. The four steps of this framework are elaborated upon in sections 3.3 - 3.6. Attempts in literature to model survival rates to time since collapse are given in section 3.7. Section 3.8 summarizes and gives the logistical requirements based on the insights given in this chapter.

3.2 The Chain of Survival: four steps

Treatment of OHCAs can effectively be done by following steps, often referred to as '**The Chain of Survival**' (Hollenberg et al., 2013):

- Recognition
- Cardiopulmonary resuscitation (CPR)
- Defibrillation
- Advanced Life Support (ALS)

These four steps serve as framework for the remainder of this chapter in sections 3.3 - 3.6.

3.3 Step one: Recognition

The first step in the Chain of Survival is recognition. Some OHCAs have symptoms prior to the collapse. Unfortunately, these are often not recognized (Müller, Agrawal, & Arntz, 2006). The most occurring symptoms are angina pectoris, dyspnea, nausea and dizziness. Due to poor recognition of symptoms, most of the OHCAs still come unexpected to bystanders.

3.3.1 Witnessed status

There are three kinds of OHCA witnessing:

- Unwitnessed
- Bystander witnessed
- EMS crew witnessed

Witnessed OHCAs, by either bystanders or EMS crew, have a much higher survival probability than the unwitnessed ones. The ORs compared to unwitnessed OHCAs are shown below. The ORs are pooled from the bottom 20% and top 20% of baseline survival.

Pooled odds ratio (95% C.I.)	Low baseline survival rate	High baseline survival rate
Bystander witnessed 95539 cases	4.4 (1.8 - 10.8)	0.3* (0.1 - 4.4)
EMS crew witnessed 83229 cases	6.0 (4.1 - 8.9)	1.7 (0.6 - 4.3)

Table 2: odds ratios for various witnessed types and baseline survival rates (Sasson et al., 2010)**. * = The lower 80% baseline survival rates all have ratios considerably larger than 1.**

3.3.2 Location

The location of an OHCA also influences the survival probability. Studies show that 63% - 79% of the OHCAs occur at home (Mader et al., 2012), (Lyon, Cobbe, Bradley, & Grubb, 2004). The OR of survival from publicly occurring OHCAs compared to those at home is 1.4 - 2.5 (Axelsson et al., 2012), (Mader et al., 2012), (Weisfeldt et al., 2011). Public OHCAs have better survival rates, because it leads to higher witness exposure, which increases the probability of timely care.

3.3.3 Patient characteristics

Age is another factor that influences survival probability: being older is worse. There is no consensus about the exact association; some studies report only minor significant difference, others report a big one. Race is another one: being black is worse than white. The difference remained significant, after correction for lower amounts of witnessed arrests, received bystander CPR, initial shockable rhythms, and hospital admission (Becker et al., 1993). Gender does not influence the survival probability. However, OHCAs do occur two to three times more at men than women.

3.3.4 Calling the emergency number

The survival probability also strongly increases when the victim or witnesses call the emergency number, because the probability of timely care from professionals is strongly increased. The emergency number to be called in the Netherlands is the European Emergency number 112. In the Netherlands, this number is known by 94% of the people of 15 years and older (TNS Political & Social, 2012).

3.4 Step two: cardiopulmonary resuscitation

The second step in the Chain of Survival is to perform cardiopulmonary resuscitation (**CPR**), which consists of providing chest compressions to the victim, and optionally breaths. CPR is effective for two reasons. First, it creates a small artificial blood circulation, which slows down damage to brain tissue. Second, it slows down the degradation of heart rhythms into asystole[6], which should be avoided.

3.4.1 How to give CPR

There are two main types of CPR: the first one is 'normal' CPR, which means that both breaths and chest compressions are provided. The second one is chest compression-only.

The practices for normal CPR do not vary much between countries. Common practices are to apply chest compressions and breaths in a 15:2 or 30:2 ratio, with compressions being at least 5 cm deep, 100 times per minute (American Heart Association and International Liaison Committee on Resuscitation, 2000).

Chest compression-only CPR is often thought to be effective enough, because it leads to blood circulation and oxygen transport to organs. This is because each recirculation of blood only subtracts a proportion of the oxygen from the blood. Scientific results for its effectiveness vary: compared to normal CPR, chest compression-only CPR may be not as effective (L Wik, Steen, & Bircher, 1994), just as effective (Svensson et al., 2010), or sometimes more effective (Hüpfl et al., 2010). A recent study confirms that compressing with the right frequency and depth may be more important than providing breaths (Infinger, Keith, Studnek, Young, & Vandeventer, 2013). This is because untrained bystanders often provide breaths erroneously. Also, a nurse on the phone is better able to give compression directions than breaths directions. A second reason to not give breaths is delay because of fear for diseases: even trained instructors hesitate in 40% of the times to provide breaths to unknown people (Hollenberg et al., 2013).

3.4.2 When to start with CPR

Literature unanimously agrees upon the fact providing CPR is better than not providing CPR. There is also agreement that CPR is especially effective when started between 0-4 minutes after the collapse. During that time, oxygen levels in the blood are still high, and can be kept fairly high if CPR is initiated. However, opinions do differ about the moment up to when CPR remains effective. The most studies suggest that it can be useful to begin even after 10 to 12 minutes after the collapse (Cummins, Eisenberg, Hallstrom, & Litwin, 1985), (Mullie, Hoeyweghen, & Quets, 1989). After 12-13 minutes, the survival probability is nearly 0%, so beginning CPR after that is mostly futile (Larsen, Eisenberg, Cummins, & Hallstrom, 1993), (American Heart Association and International Liaison Committee on Resuscitation, 2000).

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[6] Heart rhythms are explained in section 3.5.1.

3.4.3 Who should give CPR

Since the majority of the OHCAs happen at home or on the streets, a victim depends on bystanders for first help. These may give either no CPR, low-quality CPR or high-quality CPR. In general, bystander CPR increases the survival probability greatly. The pooled ORs for the lowest and highest baseline survival range from 5.0 to 1.2, respectively (Sasson et al., 2010). The survival also depends on the quality of the CPR provided: it is reported that high quality CPR versus low quality CPR has an OR of 3.4 (Gallager, Lombardi, & Gennis, 1995). Other studies also report that high-quality CPR has better survival rates than low-quality CPR (L Wik et al., 1994). Hence, EMS crew or trained bystanders should do the CPR, if available. Otherwise, it is better to have untrained bystanders begin anyway.

3.5 Step three: Defibrillation

The third step in the Chain of Survival is to defibrillate the patient. **Defibrillation** is the act of applying electrical energy to the heart through a special device, a defibrillator. This electrical shock depolarizes a critical mass of the heart muscle, terminating the dysrhythmia and starts the return of spontaneous circulation (**ROSC**). Whether defibrillation is successful depends on the type of heart rhythm and the expired time after the collapse.

3.5.1 Heart rhythms

A much-used classification of rhythms is the following (Petrie et al., 2001):

'Shockable' rhythms:
- Pulseless ventricular tachycardia (**pVT**). The ventricles are beating in an organized fashion, but too fast to create blood circulation output.
- Ventricular fibrillation (**VF**): the ventricles are contracting in a disorganized manner, in such that there is no blood flow.

'Non-shockable' rhythms:
- Pulseless electrical activity (**PEA**): there is electrical activity in the heart, but no physical contractions.
- Asystole: there is not any electrical and heart muscle activity.

Only shockable rhythms respond adequately to defibrillation. The non-shockable rhythms can sometimes be converted to a shockable one, through a combination of CPR and cardiac stimulant drugs. The pooled ORs for the bottom 20% and top 20% baseline survival rates, versus the overall survival are as follows (Sasson et al., 2010):

Pooled odds ratio (95% C.I.)	Low baseline survival rate	High baseline survival rate
pVT / VF	20.6	2.9
82854 cases	(12.6 - 33.7)	(1.1 - 7.6)
Asystole	0.1	0.2
23202 cases	(0.0 - 0.3)	(0.1-0.3)

Table 3: odds ratios for various rhythms and baseline survival rates (Sasson et al., 2010)**.**

Unfortunately, this meta-study did not compare PEA rhythms. However, other studies show that PEA scores slightly better than asystole, but well below pVT/VF, with ORs of 0.1 - 0.5 (Mader et al., 2012), (Kudenchuk et al., 2012), (O'Keeffe, Nicholl, Turner, & Goodacre, 2011), (Engdahl, Bång, Lindqvist, & Herlitz, 2001).

3.5.2 Post-collapse rhythm deterioration

Heart rhythms are highly time-dependent, since the amplitudes of rhythms decrease over time and eventually turn into asystole. Hence, the probability of successful defibrillation is extremely time-dependent. The largest meta-analysis that studied compositions of rhythms upon detection shows 1% pVT, 18% VF, 5% other shockable, 19% PEA, 45% asystole, and 12% other non-shockable (Mader et al., 2012). However, this is contradictory with much literature, stating that VF is the most detected rhythm. It has also extensively been shown that earlier detection of the rhythm by bystanders or crew can increase the probability of detecting VF up to 82% (Hollenberg et al., 2013), (Axelsson et al., 2012), (Herlitz, Engdahl, et al., 2005).

Section 3.7 lists some known VF probability formulas as a function of time.

3.5.3 When to defibrillate

Just like CPR, defibrillation is most effective when applied immediately, because the high oxygen levels in the body generally cause pVT/VF amplitudes to be bigger (Weaver et al., 1985). The probability that defibrillation effectively depolarizes the heart is highly related to this amplitude size. Because CPR indirectly leads to a slower decrease of amplitudes of pVT/VF rhythms, there is a high interdependency between those two interventions. Literature is indecisive in quantifying this interdependency, but there is consensus that CPR does prolong the time window considerably. Most studies report relatively high survival probabilities if defibrillation occurs before 8 minutes after the collapse. Early defibrillation is also desirable because less irreversible (brain) damage has occurred since the collapse, highly improving the quality of life after recovery.

There are much more factors that determine whether defibrillation is successful, but these are too medically specific to be treated here[7]. Some of those depend on the interventions itself: for example, an unsuccessful

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[7] The interested reader is referred to (Firoozabadi, Nakagawa, Helfenbein, & Babaeizadeh, 2013)

defibrillation shock negatively influences the probability of success for subsequent shocks (Callaway et al., 2001).

3.6 Step four: Advanced Life Support

The fourth and last step in the Chain of Survival is to provide the patient with advanced life support (**ALS**), which includes operations such as intubation, setting up an infusion and providing the patient with medicines. In contrast with CPR and defibrillation, which can sometimes be done by bystanders, ALS can usually exclusively be provided by EMS crew or other medical professionals. Another reason why EMS crew is very important, is because of the high probability of another cardiac arrest a few minutes after a successful defibrillation (Callaham, Braun, Valentine, Clark, & Zegans, 1993).

3.6.1 EMS response times

Shorter response times of EMS providers primarily increase survival probability because it leads to a higher probability of shorter times until defibrillation (Sund, 2013), (Pell, Sirel, Marsden, Ford, & Cobbe, 2001). ALS is especially important for non-shockable rhythms, because usually only EMS crew has access to the cardiac stimulant drugs that are needed to attempt conversion to shockable rhythms. Below is a list of studies that specifically investigated the relation between the response time of an EMS provider and survival probability.

Study	Baseline survival	survival if 1 min faster	Relative increase
(Sund, 2013)	3.9%	4.6%	18%
(O'Keeffe et al., 2011)	2.6%	3.2%	23%
(De Maio, Stiell, Wells, & Spaite, 2003)	5.9%	7.5%	27%
(Pell et al., 2001)	6.2%	6.6%*	6%*
(Gold, Fahrenbruch, Rea, & Eisenberg, 2010)	34.8% (VF only)	41.6%*	20%*

Table 4: overall hospital discharge survival rates if the response time requirement was to arrive 1 minute earlier. * = linear extrapolation.

3.7 Survival curves

There have been several attempts to explicitly model the behavior between time and survival: survival probability curves.

3.7.1 Survival probability curves (for VF/VT)

The most-quoted survival curve is the one mentioned in the Circulation 2000: 102 edition part 4, which shows the following figure (American Heart Association, 2000):

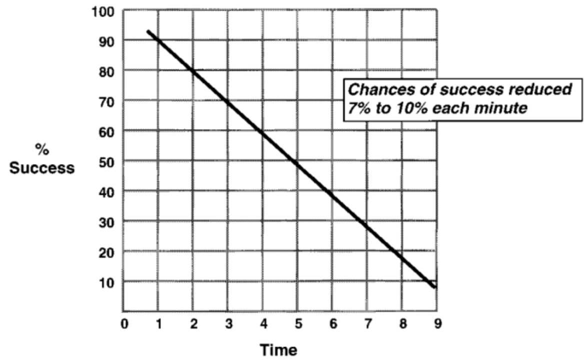

Figure 1. Composite data illustrating relationship between probability of survival to hospital discharge (indicated as "success" in figure) after VF cardiac arrest and interval between collapse and defibrillation. Based on data from Reference 41.

Figure 4: survival curve according to the American Heart Association.

This curve from the American Heart Association implies that there can be no survivors after 10 minutes, although there is widespread evidence in literature that contradicts this. The curve is said to be based on (Larsen et al., 1993), but that study estimates an initial survival rate for VF patients of 67% initially, with a 5.5% decline per minute. Other studies have found the following initial survival rates:

- 100% (Hossack & Hartwig, 1982)
- 86% (Camp & Peterson, 1986)
- 80% (Haskell, 1978)
- 74% (Valenzuela et al., 2000)
- 66% (Herlitz, Aune, et al., 2005)

The reason why these numbers are so different, is because it is difficult to correct for all possible variables. Hence, many curves include various shares of bystander CPR, quality of CPR, EMS tier system, witnessed statuses, and use different survival time measurements. Below are recent attempts to create survival probability curves:

- $100 - 10t$ (American Heart Association, 2000)
- $67 - 5.5t$ (Larsen et al., 1993)
- $46.6 - 2.83t$ (Weaver et al., 1986)
- $62e^{-0,13t}$ (Sund, 2013)
- $60e^{-0.18t}$ (Holmberg et al., 2000)
- $63e^{-0.28t}$ (Wik et al., 2003)
- $38e^{-0,24t}$ (De Maio et al., 2003)

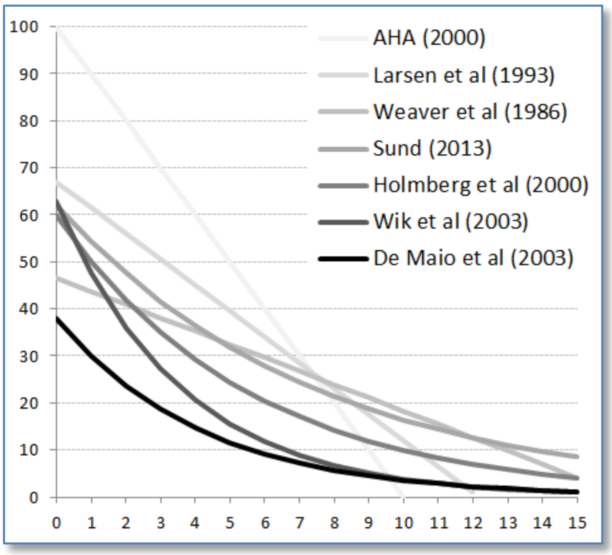

Figure 5: survival probability curves at t minutes since collapse, from different studies.

3.7.2 Adjusting for CPR / no CPR

The previous functions do not correct for the effects of CPR. However, the probability of finding a VF rhythm is dependent on CPR. There are two studies who have tried to explicitly model this behavior. The probability to find VF at some time t (minutes), if no CPR is provided:

- 75 - 3.00t [0 < t < 25] (Waalewijn et al., 2002)
- 80 - 2.70t [0 < t < 29] (Holmberg et al., 2000)

If CPR were to be applied since the moment of the collapse the equations would become as follows:

- 75 - 1.33t [0 < t < 25] (Waalewijn et al., 2002)
- 80 - 1.05t [0 < t < 25](Holmberg et al., 2001)

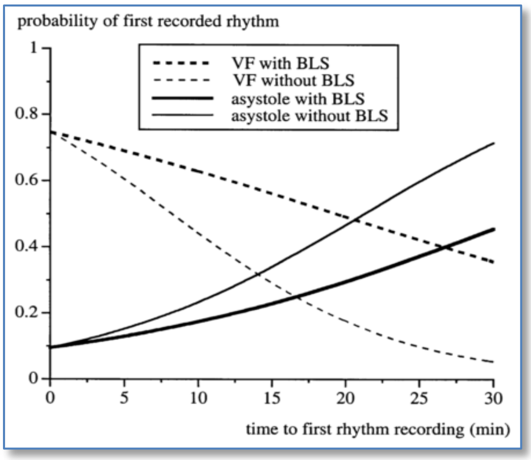

Figure 6: heart rhythm time functions, subject to CPR (Waalewijn et al., 2002)**.**

Hence, the beneficial impact of CPR on finding VF is estimated to be 3.00% - 1.33% = 1.67% (Waalewijn et al., 2002) or 2.70% - 1.05% = 1.65% (Holmberg et al., 2000).

One study (Larsen et al., 1993) estimated the impact of CPR *directly* upon survival (not the probability of finding a VF rhythm); it found a decrease of 3.3% per minute if CPR is given, compared to 5.5% if no CPR is given.

3.7.4 Survival depletion for non-shockables

Survival for non-shockable rhytms is very low, regardless of the time since collapse. Meta studies report survival rates of 0.0% to 8.4% (Sasson et al., 2010) and 1.2% to 14.0% if all non-VF/VT rhythms are included (Sandroni, Nolan, Cavallaro, & Antonelli, 2007). There is only one study that has estimated survival for non-shockable rhythms dependent on time (Petrie et al., 2001): a response time shorter than 8 minutes has 0.2% survivors, otherwise there are 0.0% survivors.

3.8 Summary: logistical requirements

This chapter has shown that an effective treatment is possible if the following logistical requirements are met:

- Apply each step within a specific **time** window,
- by specific **resources** at the scene,
- with the **knowledge** to do so.

Hence, the logistical challenge is to deliver the appropriate resources and knowledge to the scene quickly after a collapse, within appropriate time windows. This creates the following logistical interpretation:

- **Recognition**: within 4 minutes, there needs to be some resource at the victim, capable of recognizing an OHCA.
- **CPR**: within 4 minutes, there needs to be some resource at the victim physically capable of applying heart compressions. This should be done with 100 compressions per minute, 5 cm deep. As there is no consensus in literature about the benefits of providing breaths, this should only be done if the CPR is given by a professional.
- **Defibrillation**: within 8 minutes, there needs to be some resource capable of defibrillating the patient with the right technique. If the heart rhythm is non-shockable, there need to be cardiac stimulants and other tools to try to convert the rhythm to a shockable one.
- **ALS**: within 12 minutes, there needs to be some resource at the victim, capable of providing ALS and post-defibrillation care with the right technique.

This may be visualized as follows:

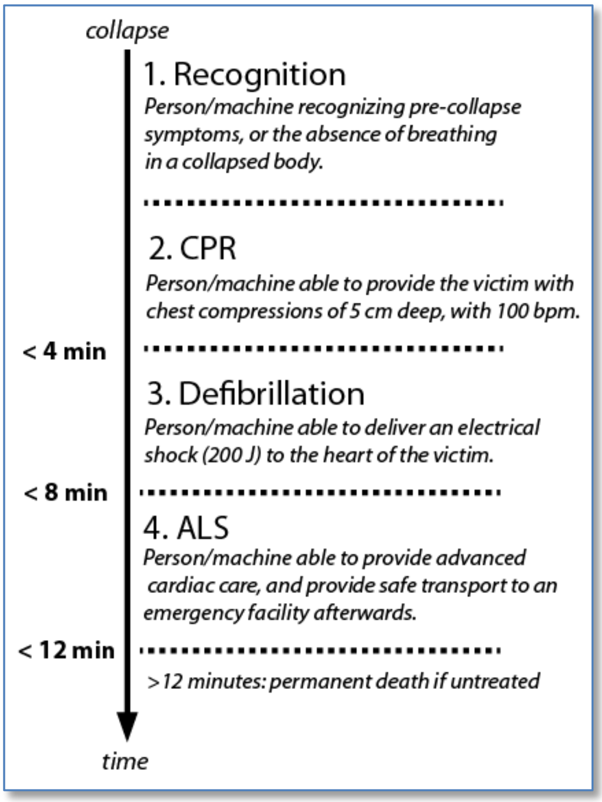

Figure 7: logistical requirements for the four steps in the Chain of Survival.

4. Emergency Medical Services Design

4.1 Introduction

The previous chapter provided both knowledge about survival factors related to OHCAs as well as showing that the logistical challenge is to bring the required resources and knowledge to the victim within a certain time window (review section [**3.8**]). As the company stakeholder of this thesis is UMCG Ambulancezorg, this chapter aims to translate those requirements to EMS design paramaters. Hence, the question that will be answered in this chapter is: *What are relevant design parameters for UMCG Ambulancezorg?*

4.1.1 Literature search approach

The literature search was conducted in the same search engines as Chapter 3. Similarly, the approach was to identify reviews and meta-analyses and use the references to explore further. The initial used papers were (Brotcorne, Laporte, & Semet, 2003), (Goldberg, 2004), and (Li, Zhao, Zhu, & Wyatt, 2011). For this chapter, the used search phrases included combinations of {review, meta, EMS, ambulance, response time, allocation, dispatching, relocation, covering, CPR, defibrillation}. After filtering for relevance and usability, this literature search identified 42 relevant papers.

4.1.2 Primary and supplementary networks

This chapter is seperates between the **primary network** and **supplementary networks**. The primary network is under full control of UMCG Ambulancezorg and therefore deals with the configuration of posts, vehicles, staff and control logic. Supplementary networks are within less control of UMCG Ambulancezorg, but may be used to further improve responsiveness. The supplementary networks considered are those of the police, firefighters, volunteers and AEDs.

4.2 Primary network setup

Literature shows that an EMS provider can reduce response times by making the correct decisions for the following elements:

- Post locations [**4.2.2**]
- Vehicle decisions [**4.2.3**]
- Staffing [**4.2.4**]
- Control logic [**4.2.5**]

Finally an EMS provider may actively use supplementary networks to further improve responsiveness [**4.3**].

4.2.1 Implications of care strategy

Some of the design parameters are predefined by some degree through the choice of the care strategy of the EMS provider. There are two main strategies (Smith & Conn, 2009). The first one is *Scoop and Run*: the casualties receive hardly any care at the incident scene and are transported as quickly as possible to an emergency facility. The second one is *Stay and Play*: casualties receive as much care as possible at the scene and are transported to an emergency facility only after complete stabilization. The Stay and Play strategy requires higher educated personnel and more advanced equipment on the vehicles, since more care is given on-scene. Which strategy yields lower mortality rates is still unclear and hard to assess, because results are difficult to compare and controlled trials are difficult to conduct in regions with set EMS protocols (Haas & Nathens, 2008).

4.2.2 Post locations

There are three main tactics in determining post locations. The first one is using a **call hotspot** location strategy. This means that ambulance posts are situated in areas where many calls occur. This approach works well if there is historical data, so that an EMS provider knows where the calls came from. For networks that need to be built from scratch, a (expected) correlated measure needs to be taken, such as population density. An advantage of this strategy is that it allows for economies of scale, by merging posts in dense call areas.

Another strategy is using a **main infrastructure** location strategy. In most cases this implies situating posts at (the entrances of) highways, but it may also be at infrastructure hubs, such as ports or airports. The idea behind this strategy is that the speed of vehicles contributes more to good performance than close average distance. This strategy is especially useful when the calls are dispersed across a larger area, which is the case in areas with a low population.

A third strategy is a **risk-based** location strategy. This is not necessarily the same as a call hotspot strategy, as risks may be more temporal and lead to certain types of incidents. This allows for vehicle specialization, suited for the specific kinds of incidents. A risk-based location strategy may be part of trying to prepare for large scale incidents (Elliott, 2010). Examples of this strategy are ambulance posts at large industry complexes, due to a higher risk of multi-casualty incidents. Another example is creating a temporary post at a multi-day event.

4.2.3. Vehicle decisions

There are three decisions to be made when it comes to vehicles:

- Vehicle system: single-type or tiered

- Functional types: emergency-only, or more
- Physical types: detailed mix of vehicles

Vehicle system

There are two types of vehicle systems when it comes to the vehicle mix (Stout, Pepe, & Mosesso, 2000). The first one is the **single-type** vehicle system. The second one is the **tiered** vehicles system. In the single-type vehicle system, all vehicles are advanced life support (**ALS**) vehicles with highly-educated staff, which can perform all possible operations. In the tiered vehicle system, there are different types of vehicles. Usually there are two types: ALS vehicles and basic life support (**BLS**) vehicles. The BLS vehicles are less advanced and can be operated by lower educated staff.

The single-type system has higher training costs for staff. However, the tiered system requires a more complicated dispatching system, and hence, costs. Therefore, the tiered system is not necessarily cheaper.

The tiered system generally has longer response times. This is especially the case for remote areas, because BLS vehicles cannot be sent to urgent incidents, so ALS vehicles need to come from further away. However, in tiered systems having aircrafts, the performance can dramatically increase, especially when facilities are far away (Assa, Landau, Barenboim, & Goldstein, 2009), (Zarei, Yarandi, Rasouli, & Rahimi-movaghar, 2013). However, other publications note that this gain in response time does not necessarily translate to a gain survivability, since the in-hospital times usually become longer (Bulger et al., 2012). In tiered systems, the higher educated staff on ALS vehicles usually has higher competence levels compared to those in a single-type system. This is because they spend more time exclusively on ALS work and the BLS work is done much as possible by their lower-educated colleagues.

Functional vehicle types

There are three options: **emergency** vehicles, **rapid responders** and **transport-only** vehicles. Emergency vehicles refer to the majority of vehicles, designed to bring crew to the scene and perform patient transport if needed. Rapid responders are non-ambulance vehicles, and their purpose is not to transport patients, but to start with the first aid until other vehicles arrive. Transport-only vehicles are used for low-urgency transports, such as picking up patients that have a periodic appointment in a hospital.

Physical vehicle types

The three main types are **land** vehicles, **air** vehicles and **water** vehicles. Land vehicles exist in many variations. For example, the functional type *rapid responder* can take form as automobiles or medical emergency motorcycles. Motorcycles can introduce huge reductions in response times and costs in a congested urban setting (Patel & Ekkiswala, 2010). However, work safety is an issue as motorcycles are more vulnerable than automobiles. It is also possible to use increased-capacity vehicles. Examples of these are the ‘Booze Bus’ in London, which is used for events and at weekend nights to treat alcohol-related patients on-scene (Ghani, 2012) and the ‘Medical Ambulance Bus’, a bus used in Toronto for large multi casualty incidents. Other options which may be used: bicycles for pedestrian-only areas (Reed, 2012), horse and cart in developing countries, and hospital trains in warzones.

Air vehicles can be helicopter or airplane. Air transport is generally more expensive than land transport, especially in dense areas. However, in remote areas, with long travel distances, or when there are huge congestion problems, air transport can be very cost-efficient (Brown et al., 2012).

Water vehicles are boats, ships and hovercrafts and are used primarily for islands or areas with large lakes that have intensive water recreation.

4.2.4 Staffing

The personnel on the vehicles, the Emergency Medical Technicians (**EMT**), can be categorized into several levels. One possible classification is the following (Zarei et al., 2013):

- **First Responders** can preserve the airway, perform assisted ventilations, CPR, and can control bleeding.
- **EMT-Basic** can perform patient assessment, deliver oxygen, immobilize the spine, and transport the victim.
- **EMT-Intermediate** can perform basic life support and use automated external defibrillators.
- **Paramedics** have received the highest amount of emergency medical education. They are trained to obtain vascular access and deliver medications via inhaled, intraosseous, intravenous, intramuscular and endotracheal routes and perform endotracheal intubation.

There are more levels that can be recognized. For example, some EMS providers may employ dedicated ambulance drivers. Also, a paramedic may receive further training and become an Emergency Care Practitioner to bridge the link between ambulance care and general care practitioners. Finally, doctors can be on vehicles to transport the highest amount of expertise to an incident scene.

4.2.5 Control logic

The control logic can be split into many elements. The most important ones are **dispatch** logic and **relocation logic**.

Dispatch logic

The dispatch logic is one of the elements that determine whether any response is effective (Mayorga, Bandara, & McLay, 2013). Dispatching is the act of sending a particular ambulance to an incident. This act can be further decomposed into three smaller sub-problems (Lim, Mamat, & Braunl, 2011):

Call queuing is the first thing that happens. Here, there are roughly two methods: *first in first out (FIFO)* call queuing or a *priority based* call queuing. In the first approach, ambulances will always be assigned in the same sequence as the incoming calls. The second approach dispatches ambulances for the most urgent calls first, before the less urgent calls.

Ambulance assignment is the second sub-problem. Possibilities here are to use a *closest-ambulance* assignment, a *coverage-with-probability* assignment, or a *coverage-with-preparedness* assignment. In the latter two the system coverage, combined with a probability of busy ambulances or another preparedness construct is used to determine which ambulance is assigned.

Add-on mutations are adaptations to an initial dispatch. These are not necessary, but can be used to make changes on-route. A *reroute-enabled mutation* reroutes the active ambulance to another incident to improve average response time. A *priority-update mutation* changes the urgency of a call, for example to allow higher vehicle speeds. A *just-finished mutation* sends ambulances which are just returning from the hospital, instead of awaiting their return to the post. This last add-on mutation exploits the fact that these ambulances have no mobilization time.

Older models (before 1980) generally use FIFO call queuing, assign the closest ambulance, and have no add-on mutations. The next generation of models (1980-2000) have alternate call queuing and probabilistic elements. Most of the recent models are *dynamic* models: models that react to changes in the system. They often include priority-based call queuing, combined with a coverage-with-probability or coverage-with-preparedness assignment. The interested reader is referred to Appendix [**B**] for a list of important models.

Relocation logic

Relocating an ambulance is the act of moving an ambulance preventively in an attempt to achieve better coverage. It is also known as redeployment, system status management, move up, or dynamic positioning. Relocations happen after selected system changes, such as incidents or vehicle movements. This means that the system status constantly needs to be monitored and recalculated in order to achieve optimality in response times or coverage (Brotcorne et al., 2003). Note that relocations do not need to be system-wide, but can also be limited to returning ambulances only. This may be necessary when regulation forbids other relocations (Schmid, 2012).

Relocations can dramatically improve response times (Alanis, Ingolfsson, & Kolfal, 2013). For example, a simulation study for the Edmonton EMS system showed that a strategy without relocations would require eight additional ambulances to achieve equal performance. The increase in response time performance ranges between 1% and 6% (Nair & Miller-Hooks, 2009). However, there can be counterproductive effects too, like reduced rest time during a shift, increases in workload, and fatigue (Henderson, 2011). Therefore, the successful implementation of a successful relocation strategy is not very straightforward. There are three types of relocation plans (Saydam, Rajagopalan, Sharer, & Lawrimore-belanger, 2013):

No relocations. This implies that ambulances always return to a fixed position; system changes have no influence. Note that in model terminology this implies using a static (classical) model. The amount of EMS providers that do not use a relocation plan is declining. Between 2002 and 2009 the share of EMS providers using a static deployment declined from 41% to 30%, whereas the share using relocation plans increased from 23% to 37% (Alanis et al., 2013).

Multi-period. In multi-period relocation plans, relocations are scheduled for a longer period of time. This period may be a few hours (Schmid & Doerner, 2010), a half day (Rajagopalan, Saydam, & Xiao, 2008) or longer, up to a few weeks. The relocations are based on call patterns, traffic patterns (Schmid & Doerner, 2010), or movements of classes of people (Reuter & Michalk, 2012).

Real-time. In real-time relocation plans, relocations are planned on very small system changes. This type of relocation plan is considered to be the most accurate, and is becoming very popular in recent years due to technological advances in data processing technology. Typical system changes that trigger relocations in these relocation plans are: incoming calls and current ambulance positions (Andersson & Värbrand, 2007), (Lee, 2010), or suddenly changing demand volume (Zayas-Cabán, Lewis, Olson, & Schmitz, 2013), ambulances becoming available again, or busy low-priority ambulances that reroute to pick up a second patient during high demand (Majzoubi, Bai, & Heragu, 2012). Another example is to temporarily assign other vehicles to avoid congested roads (Sisiopiku & Cavusoglu, 2012).

Relocations plans require accurate data about the status and location of vehicles. Therefore, a structured data gathering and storage system needs to be used. For the real-time relocation plans a Geographic Information System (**GIS**) is essential. Control centers often use a relocation plan together with a compliance card to simplify the relocation process. A compliance card lists the most preferable system configuration under a given number of available vehicles. The dispatcher will then continuously try to match the desirable system configuration by moving idle vehicles to other facilities (Alanis et al., 2013).

Technically, there are three approaches for relocation models (Matthew S Maxwell, Henderson, & Topaloglu, 2009), (Li et al., 2011): solving an integer program in real-time, calculating beforehand the optimal vehicle locations for a given amount of available vehicles (Alanis et al., 2013), or through explicit modeling of randomness in the system to estimate the most likely short term system changes.

4.3 Supplementary networks

4.3.1 Introduction

The previous section identified options for the design parameters that are fully within control of an EMS provider: post locations, vehicle decisions, staffing and control logic. However, survival rates may be much higher and with better cost-effectiveness if external first-responders are used (Blackwell & Kaufman, 2002), (Nichol et al., 2003). The response time varies inversely as the square root of the number of ambulances per square area, meaning that at some point adding ambulance (posts) is an extremely inefficient solution (Wang, Link, Homoud, Estes, & Page, 2001). Recent studies confirm that approaches including multiple networks are efficient in terms of the cost per life saved (Sund, Svensson, Rosenqvist, & Hollenberg, 2011).

4.3.2 Police and/or firefighters

A first secondary network option is those of another rescue services provider, such as **police** or **firefighters**. Studies report that the EMS network may be extended with either one of them or both. For example (Sund, 2013) predicts that the amount of survivors would increase from 3.9% to 6.3% if the fire services vehicles are included as well. A study in the region of Amsterdam in the Netherlands also reports that the police arrives at least 5 minutes earlier than EMS vehicles in 16% of the cases (R a Waalewijn, de Vos, & Koster, 1998); hence, the author suggests to equip all the police cars with defibrillators. Many regions already use a dual EMS/fire services dispatch system for OHCAs. Examples are King County (Gold et al., 2010), Birmingham (Sisiopiku & Cavusoglu, 2012) and Hanover (Toro-Díaz, Mayorga, Chanta, & McLay, 2013).

4.3.3 Volunteer network

A network of **volunteers**, which can perform bystander CPR is found to be a major contributor to recently improved survival rates in Norway (Lindner, Søreide, Nilsen, Torunn, & Lossius, 2011).

4.3.4 AED network

An automated external defibrillator (**AED**) network is another option. Studies show that huge improvements have been achieved or may be expected by equipping fire trucks (Hollenberg et al., 2013) or police cars (R a Waalewijn et al., 1998). They can also be placed in public places. Here, the choice can be made whether its use is intended for trained professionals (Valenzuela et al., 2000) or also for untrained bystanders (Whitfield et al., 2005). In all cases, the survival rates increase by using an AED network.

4.4 Overview of design parameters

4.4.1 Primary network design parameters

1. Post locations	**Call hotspot** **Main infrastructure** **Risk-based**
2. Vehicle decisions	
- System	Single-type Tiered
- Functional:	Emergency Rapid responders Transport-only
- Physical:	Land Air Water
3. Staffing	First responder EMT-basic EMT-intermediate Paramedic
4. Control logic	
- Call queuing	First in, first out Priority based
- Ambulance assignment	Closest ambulance Coverage with probability Coverage with preparedness
- Add-on mutations	Reroute-enabled Priority-update Just-finished
- Relocations	None Multi-period Real-time

4.4.2 Secondary network design parameters

1. Rescue services	None Fire services Police Both
2. Volunteers	None Yes
3. AED	None Fire trucks Police cars Public places

5. Current system design

5.1 Introduction

Chapter 3 provided more insight about all the factors that influence survival of OHCAs. The key observation in that chapter was that *time* is an extremely important factor. Hence, that chapter was finalized with time-dependent survival curves in section [**3.7**] and a comprehensive scheme, listing the key actions that need to be taken in certain time windows in section [**3.8**]. Next, Chapter 4 set out to find design parameters for an EMS provider in section [**4.2**], as well as listing supplementary networks in section [**4.3**].

This chapter will answer the third research question: *What is the current system design?* Hence, this chapter describes the current system in terms of the design parameters as listed in section [**4.4**]. These have also been summarized in the Activity Block in the conceptual model from Chapter 2, which is shown again below for convenience.

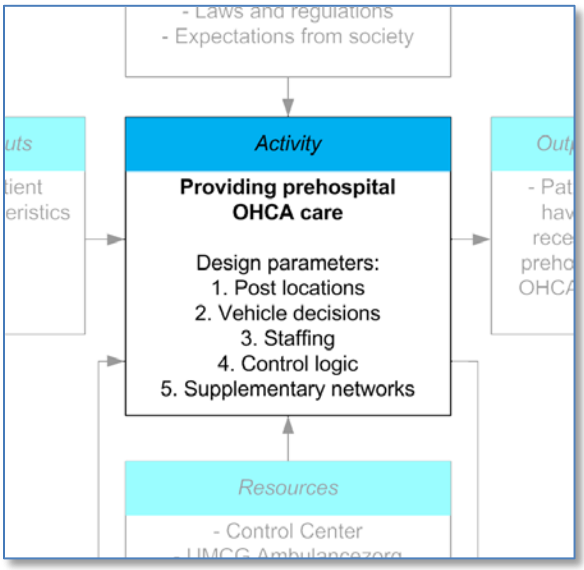

Figure 8: excerpt from conceptual model: the Activity Block

5.2 Post locations

UMCG Ambulancezorg has 13 posts throughout the province of Drenthe[8]: Annen, Assen, Beilen, Borger, Coevorden, Dieverbrug, Emmen, Emmen Noord, Hoogeveen, Klazienaveen, Meppel, Roden, and Tynaarlo.

Figure 9: ambulance post locations in Drenthe.

The current post location strategy is a hybrid of a call hotspot strategy and main infrastructure strategy, as will be explained in more detail in the next chapter.

5.3 Vehicle decisions

5.3.1 Vehicle system

UMCG Ambulancezorg has a tiered vehicle strategy. The largest share of the vehicle fleet consists of ALS vehicles. These respond to A1, A2 and B calls[9]. The other vehicles are BLS vehicles and respond to B calls that are pre-scheduled transportation. Examples of planned transport are patients that need to be brought to the hospital for a scheduled appointment, or transporting patients between hospitals. There is also one customized BLS vehicle, especially created for obese patients. There are also vehicles especially for supporting internal operations, such as a truck that delivers work materials throughout the province.

5.3.2 Functional types

The ALS vehicles are all emergency vehicles. They are designed to provide care in most circumstances. Exceptions apply when patients need to undergo highly complex medical operations. A common example of such an operation is bringing the patient under narcosis. This is only allowed by staff from the Mobile Medical Team (**MMT**). In the Netherlands, there are eleven trauma centers that have such a team[10].

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[8] Situation as in early 2013. Recently, Westerbork has been added.

[9] B1 calls. This is a sub category of B calls and was recently introduced to distinguish between non urgent calls (B1) and pre-scheduled transportation (B2).

[10] The closest trauma centers with a helicopter are situated in Amsterdam, Nijmegen and Groningen.

The BLS vehicles are used primarily for planned transport, which makes them transport-only vehicles. They are usually only needed at weekdays during daytime, because hospitals tend to place transportation requests only during those times. BLS vehicles lack many more sophisticated tools and are equipped by lower-educated staff. When there is a serious supply problem of ALS-vehicles, local planned transportation for BLS vehicles may be suspended to assist the ALS vehicles. However, it is very rare in practice for this to happen.

Finally, there are a few vehicles that can be classified as rapid responders. Within UMCG Ambulancezorg, these are referred to as a 'solo'. The rapid responders take form in either a one-manned vehicle or a motorbike. These rapid responders (are supposed to) drive around a lot of the time, to reduce the mobilization time that is inherent to the non-driving vehicles.

The vehicles are spread across the bases in Drenthe. The actual amount of vehicles used at some time varies, because fewer vehicles are scheduled at night and in weekends. To give an impression, the situation below depicts the amount of vehicles that are operated from a specific post, during an average weekday during daytime.

Base	ALS	BLS	Solo
Annen	1		
Assen	3	2	1
Beilen	1		
Borger	1		
Coevorden	1		
Dieverbrug	1		
Emmen	3	1	1
Emmen-Noord	1		
Hoogeveen	2	1	
Klazienaveen	1		
Meppel	2		
Roden	1		
Tynaarlo			1
Total	**18**	**4**	**3**

Table 5: number of active vehicles during an average weekday during daytime.

5.3.3 Physical types

All vehicles that have been mentioned so far are all land vehicles. In the daily schedule, these are the only vehicles that are scheduled. However, UMCG Ambulancezorg does have some water vehicles at its disposal, which may be used for special occasions. Examples of such special occasions are large events on the water, such as the Sneekweek, or sailing events at lakes or at the Waddenzee. However, these are not relevant for the province of Drenthe, but only apply to the services that UMCG Ambulancezorg provides in the province of Friesland. This also applies to the unofficial agreement that allows UMCG Ambulancezorg to 'borrow' a helicopter from National Defense, if needed. This helicopter is located on Air Base Leeuwarden. In contrast to what many people believe, trauma-helicopters that are flying in Drenthe are not owned or operated by UMCG Ambulancezorg, but from a trauma center with a MMT-helicopter.

5.4 Staffing

All ALS vehicles are operated by two staff members. The first one is the driver. Ambulance drivers have received a training to drive an ambulance responsibly. The drivers also receive a medical education that entitles them to work as a Primary Care Paramedic. This means that they are allowed to assist in certain operations. For example, during resuscitation, the driver is allowed to perform massages, but is not allowed to inflict the electric shock through defibrillation, to intubate, or to set up an infusion.

These kinds of tasks are only allowed by the second staff member of the ALS vehicle, a highly skilled paramedic. The skilled paramedics have not received a driving education, but are specifically specialized in providing medical healthcare. They are allowed to do all operations required for resuscitations. However, as noted already, for very complex interventions, the aid of a MMT is required.

In comparison with foreign EMS providers, the Dutch system is aberrant due to the very high education standards.

The BLS vehicles, which are usually only used for planned transportation, have a different kind of staff. These are operated by 'caring' staff. These are not paramedics with specific medical expertise, but have an education and profession in the field of care. For example, many of the BLS employees have worked in nursing homes for the elderly.

5.5 Control logic

5.5.1 Call queuing

An emergency call is initiated by calling 112. Any incoming call from a fixed telephone operating through the traditional telephone network is directly connected to the closest control center. Fixed telephones operating through the Voice Over Internet Protocol, or mobile phones are first connected to the national control center of the Korps Landelijke Politiediensten. The call taker there will first ask where the call is made and will put the caller through to the appropriate local control center. The control center for the three northern provinces is the Meldkamer Noord-Nederland (**MKNN**).

Call queuing is priority-based. There are three types of priorities: A1, A2 and B[11]. A1 calls are the most urgent calls: the dispatched EMS provider needs to have at least one vehicle at the scene within 15 minutes in 95% of the cases. For A2 calls, it needs to be at the scene within 30 minutes in 95% of the cases. B calls have no response time requirement. The dispatcher will queue A1 calls before A2 and B calls, as these are more urgent. However, call queuing in practice tends to be first-in-first-out, because the call volume compared to emergency call takers at the MKNN is high: usually all of the three provinces have both a call taker and a dispatcher available, which will hand over jobs to each other if there is a second or third simultaneous call.

5.5.2 Ambulance assignment

The ambulance assignment can be done in three ways: sending the closest ambulance, taking busy probabilities into account, or using a preparedness measure. The current practices are most closely related with sending the closest ambulance.

The dispatchers at the control center are using a software environment which is called the Geïntegreerd Meldkamer Systeem (**GMS**). It provides them with information of current and historical calls, communication channels, and a map that shows the real-time location of ambulances. Another module presents the preferred ambulance to dispatch, which is called the ‘inzetvoorstel’ (**IV**). The system presents multiple IVs, with the first one being the most preferred one to choose. IVs are generated in descending distance to ambulances. The IV algorithm does not incorporate busy probabilities or any other preparedness measure. Hence, it is a closest-dispatch algorithm. IVs are presented for both A1 and A2 calls.

Dispatchers are allowed to ignore the preferred IV and dispatch a different ambulance if they have a good reason to do so. A typical example is when the dispatcher has knowledge that a closer located ambulance is about to finish a previous call. The IV algorithm will not ‘see’ this ambulance, because it is still listed as busy. Hence, the dispatcher ignores the IV and waits for the closer located ambulance to become available. In such circumstances the ambulance assignment has more resemblance with a dispatch strategy that takes busy probabilities into account.

5.5.3 Add-on mutations

All of the add-on mutations are currently practiced at the MKNN: reroute-enabled mutations, priority-update mutations, and just-finished mutations. All of these mutations are done manually, i.e. there is no system or algorithm that assists the dispatchers. There are also no strict enforced guidelines for these add-on mutations, so assertiveness, willingness and proper judgment of the dispatchers are key factors that determine whether add-on mutations take place.

5.5.4 Relocations

A relocation strategy may either be non-existent, multi-period or real-time. The current practices are a hybrid multi-period and real-time relocation strategy.

In some sense the current relocation strategy is a multi-period strategy, because it acknowledges differences during the day and night, and between working days and weekends as well: there are fewer ambulances on duty in the weekends and during the nights. An overview of the shifts can be found in Appendix [**E**]. Hence, the multi-period relocation plan only takes into account call volumes throughout day/night and weekday/weekend. Traffic patterns or movements of classes of people are currently not considered in the multi-period aspect of the relocation strategy.

There is also a real-time relocation plan that is based on coverage of the four largest cities: Hoogeveen, Emmen, Meppel and Assen (**HEMA**). This implies that ambulances further away may be moved towards any of these four cities if there are no remaining available ambulances left to cover the city. The dispatchers at the MKNN have a compliance table that lists the favorable system configurations under various loads. For example, if Assen has no more available vehicles, the table will show which of the posts should temporarily loan their vehicle to Assen until Assen has restored coverage again.

5.6 Supplementary networks

5.6.1 Police

Organization

Drenthe has 14 police posts: Assen, Assen-Balkengracht, Beilen, Coevorden, Diever, Emmen, Exloo, Gieten, Hoogeveen, Klazienaveen, Meppel, Roden, Vries, and Zuidwolde. Police vehicles are usually not scheduled to be on their posts during service hours, as they are patrolling somewhere else. Patrol zones are not restricted to specific zones, patterns or times. Therefore, police cars seem to be moving around randomly, from a system’s view. However, they are being monitored real time using GPS in the MKNN.

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[11] Since recently, B calls are further categorized as B1 (non-urgent) and B2 (prescheduled transportation).

Figure 10: police post locations in Drenthe.

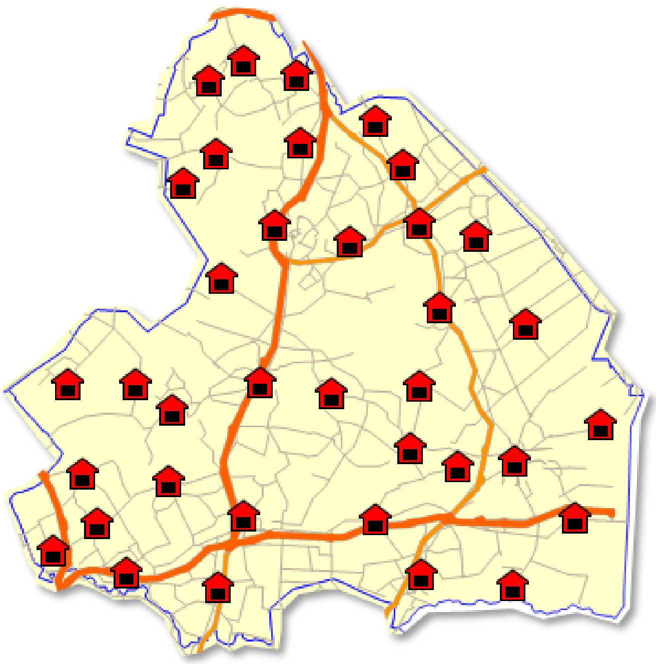

Figure 11: fire services post locations in Drenthe.

Current usage

Some of the police vehicles are equipped with an AED. Officials state that they ‘believe’ that the emergency vehicles have an AED. Recently, it has become a habit for EMS dispatchers to always ask their police colleagues at the MKNN if there is a police vehicle nearby to assist at resuscitations. If there is such a vehicle and it has no urgent matters, it will go to the location of the OHCA.

This makes police cars currently rather unreliable resources, because their location and availability are highly uncertain, even on short notice. However, multiple staff individuals from UMCG Ambulancezorg have expressed to be very happy with the police. First, they can help to calm down bystanders, so the ambulance crew can focus on their core task of providing care. Second, police officers can do the CPR, so the staff can prepare the advanced life support and do the more complicated operations in the resuscitation process. This is especially the case in the first minutes, before the second ambulance has arrived.

5.6.2 Firefighters

Organization

There are 36 fire services posts in Drenthe: Annen, Assen, Beilen, Borger, Coevorden, De Wijk, Diever, Dwingeloo, Eelde, Emmen, Emmer-Compascuüm, Gasselternijveen, Gieten, Havelte, Hoogeveen, Klazienaveen, Meppel, Norg, Peize, Roden, Rolde, Ruinen, Ruinerwold, Schoonebeek, Schoonoord, Sleen, Smilde, Tweede Exloërmond, Veenhuizen, Vledder, Vries, Westerbork, Zuidlaren, Zuidwolde, Zweeloo, and Zwinderen.

Before 1 January 2014, the fire services were under supervision by municipalities. The 36 posts are grouped in 3 districts: Northern and Central Drenthe, South-West Drenthe, and South-East Drenthe. However, direct supervision of the 36 posts is done by the 12 municipalities that control them, although the latest years the collaboration within districts has increased. Since January 1st, 2014 the 12 fire services have fused together to one organization to provide services in the safety region Drenthe, similarly like the way EMS services are provided by 1 organization.

There are three types of firefighters: professionals, volunteers, and professional support. Professionals work in shifts in barracks and will actively wait for emergency calls. The number of firefighters working as professional is minimal compared to the number of volunteers. Only large municipalities or specific high-risk areas are still working with professionals. The majority of firefighters are working as volunteer. This means that they are not stationed in barracks, but have other professions or activities during the day. If a certain post is dispatched by the MKNN, its registered volunteers that are on duty will receive a message through their pager and will hurry to their post. Hence, posts working with volunteers have longer mobilization times (4-6 minutes) than those working with professionals (1-2 minutes), according to the firefighters chief at the MKNN. The distribution is assumed to be uniform; more precise and accurate data is not readily available for all posts in Drenthe. Volunteers have the same tasks, responsibilities and education as professionals. The third type of firefighter staff is working as professional support on selected posts. They do the operational preparation, provide education and exercises and risk management.

Current usage

The MKNN does not alert fire services posts. Also, there are no vehicles or posts equipped with AEDs.

5.6.3 Volunteers

Organization

The largest volunteer database for Drenthe is the one managed by Hartslag voor Nederland in a database referred to as HartslagNu (www.hartslagnu.nl). This is a recently initiated project from several EMS providers in the Netherlands. UMCG Ambulancezorg is one of those participating EMS providers. HartslagNu has a database which contains around 3360 volunteers in Drenthe (December 2013). To register, volunteers need to go to the website of HartslagNu, and input their certificating institute, personal data and availabilities. The system allows multiple locations under multiple times, so volunteers can enter both a home and work address. HartslagNu only offers the platform for volunteer resuscitation alerts and the database; it does not educate the volunteers. This is done through the many separate volunteer organizations throughout the region.

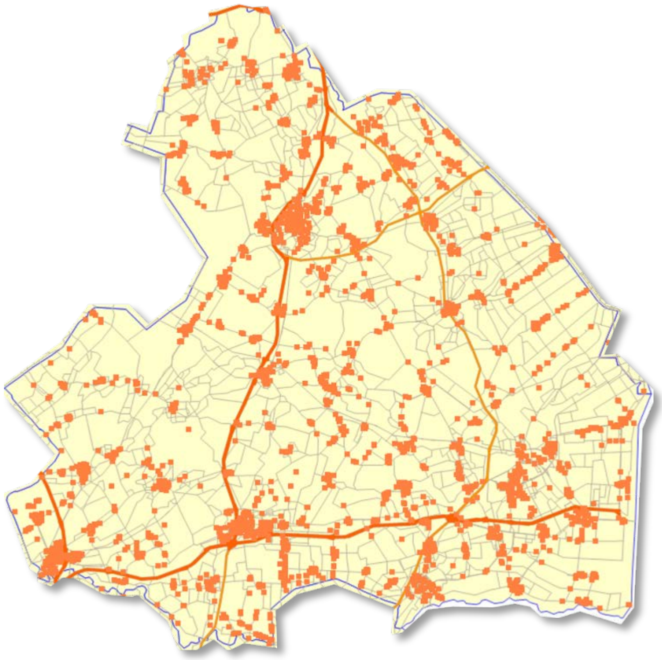

Figure 12: locations of registered and approved volunteers in the HartslagNu database.

Current usage

There is an alerting system for volunteers at the control center. The dispatcher can alert volunteers through a module in the GMS. This module automatically calculates which volunteers are within a range of 1500 meters and will send a message to the mobile phone of 30 volunteers maximum. The volunteers receive a text message, which tells them to either go to the location directly, or to collect an AED first. It has become a rather common practice to alert volunteers for resuscitation calls. In the region of Drenthe, this is not the case for traumatic cases, which are considered to be too violent for non-professionals. The number of alerts and the amount of alerted volunteers are growing:

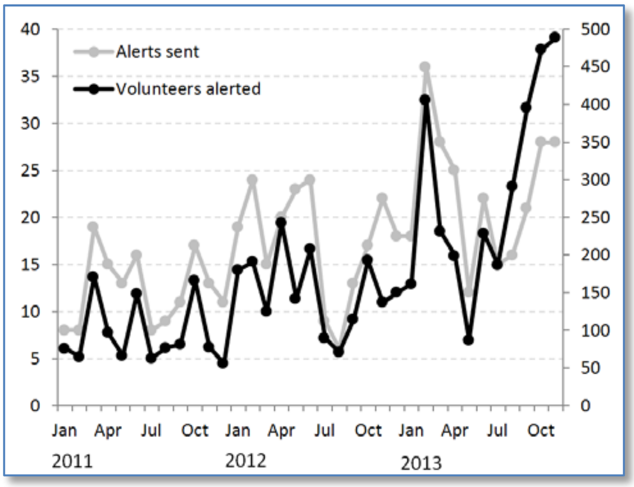

Figure 13: the number of alerts (left axis) and alerted volunteers (right axis) per month in Drenthe for 2011, 2012 and 2013 (up to November).

There is only data about the number of alerts and which volunteers have been alerted. No data is collected for actual show-ups, response times, quality of the CPR that is being provided, or other possible output measures.

5.6.4 AEDs

Organization

The largest database of AEDs is also managed by Hartslag voor Nederland in a very similar manner as the volunteers are being managed. The location, owner, availability, type, serial number, expiration date of battery, and expiration date of electricity are stored into the database. AEDs may be entirely publicly available at all times, or part-time only. This can be the case if they are located inside a building that has limited opening hours. The amount of AEDs is much lower than the amount of volunteers. Currently, there are about 230 registered and approved AEDs in Drenthe (December 2013).

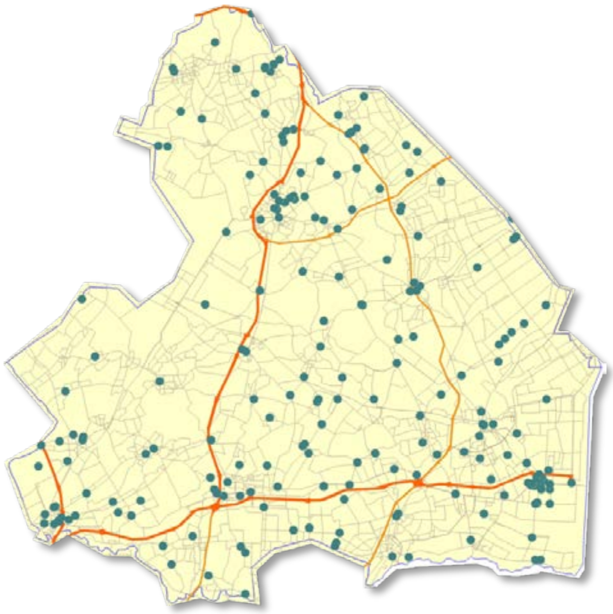

Figure 14: locations of registered and approved AEDs in the HartslagNu database.

Current usage

The module in the GMS automatically calculates which volunteers are ordered to collect an AED for a resuscitation call. Currently, it is programmed to send a maximum of 20 volunteers to an AED, out of a total of 30 volunteers. All other remaining volunteers are ordered to go to the OHCA scene directly. The actual usage of AEDs is unknown, as this data is not collected. The only data that is collected is input data: the amount of volunteers per alert that is ordered to go to an AED, and the number of AEDs involved per alert.

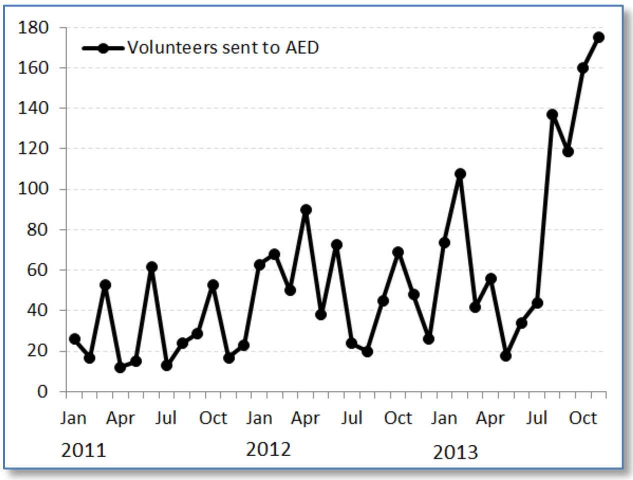

Figure 15: the number of volunteers that is ordered to collect an AED, per month in Drenthe, for 2011, 2012 and 2013 (up to November).

5.7 Summary

Below is a summary of the configuration of the design parameters, as presented in the previous chapter:

5.7.1 Primary network design parameters

1. Post locations	13 posts, situated as a hybrid call hotspot / main infrastructure strategy.
2. Vehicle decisions	
- System	Tiered system. However, OHCAs are only responded to with ALS vehicles.
- Functional:	OHCAs are always responded to with emergency vehicles. Occasionally, rapid responders are used as a second vehicle as well.
- Physical:	Only land vehicles are used in daily operations.
3. Staffing	OHCAs are served by ALS vehicles. Hence there is an EMT-Intermediate (driver) and a highly skilled paramedic. In comparison with other countries, the education level of the professionals is very high. In some cases, there may also be a first responder.
4. Control logic	
- Call queuing	Priority based on overall. However, OCHAs are always top-priority, making it a first-in first-out system for OHCAs.
- Ambulance assignment	For OHCAs: closest ambulance unless manual override by dispatcher.
- Add-on mutations	All types, so: reroute-enabled, priority-update, and just-finished. These don't occur often and only if manually done by the dispatcher.
- Relocations	Hybrid system of multi-period / real-time.

5.7.2 Secondary network design parameters

1. Rescue services	Police-only; this is to some extent as they may decline a request.
2. Volunteers	Yes, using the HartslagNu database of predefined volunteer locations. Alerting volunteers becomes more common practice and is done through a module in the GMS system.
3. AED	Public places only. There may also be AEDs available at some police cars, but these are not actively used.

6. System analysis

6.1 Introduction

6.1.1 Approach and structure of this chapter

Chapter 3 and 4 showed that the crucial element in effective treatment of OHCAs is the timely arrival of certain resources. Therefore, the main approach in this chapter is to investigate how the different system elements impact the responsiveness.

Recall that the first way to achieve better responsiveness (conceptual model in section [**2.5**]) is by having the best possible post location strategy. All strategies try to minimize the average response time, either through minimizing distances or maximizing travel speeds. To determine whether the post locations are appropriate, the demand must be known first. Hence, in section [**6.2**], the demand is mapped, into two parts: the geographical dispersion of calls [**6.2.2**], and the call volume and patterns [**6.2.3**]. In Section [**6.2.4**], the current response time performance is assessed, showing that it is currently inadequate. Section [**6.2.5**] shows that the performance hardly depends on the current variations in the call volume. This implies that stochastic effects (such as simultaneity of calls) do not need to be considered. Sections [**6.3**] up to [**6.5**] consider the other four aspects of the conceptual model from chapter 2.

Section [**6.6**] analyzes the current performance of the firefighters and police. There is no historical data about performance for these networks. However, some useful analysis is still possible due to the insights gained by analyzing the primary network. As section [**6.2**] will show, a high dispersion of posts is very beneficial for the response time performance. This makes the firefighter network very interesting due to its higher post density. The police movements can be modeled as rapid responders with random locations. To gain insight if the benefit would be especially a reduction in mobilization times, or due to potentially favorable locations an analytical simulation model in Plant Simulation was used for this section.

The performance of the volunteer network and AED network will be analyzed in sections [**6.7**] and [**6.8**]. Since there is only input data for these networks, the analysis on these networks is rudimentary and based on the insights gained in sections [**6.2**] up to [**6.6**].

6.1.2 Analyzing techniques

Demand data is collected by the control center and contains information about the exact date and time of incoming calls, the dispatched vehicle, mobilization time, and drive time. These are quantitative data and are manipulated in spreadsheet software and the data analysis environment in Optima Predict. The spreadsheet software is used to translate response time performances per minute to estimated survival probabilities (see section [**6.1.3**]). It was also used for all manual data inspection, such as linking data from UMCG Ambulancezorg with volunteer alert data from the control center. Statistical tests are done with a Statistics Toolpak in the spreadsheet software.

Optima Predict is a dedicated geographical information system and simulation solution from The Optima Corporation. The included data manipulation tools in Optima Predict allow quick evaluation of averages and distributions on many measures. For example, the distribution of response times or mobilization times can be quickly assessed. This can be done for the total dataset, or for repeating intervals, such as daily hours. This simulation software also has a built-in road network with tuned network speeds based on vehicle speed data collected by the EMS vehicles. Hence, it allows the user with powerful simulation tools to test scenarios. This software also has graphically oriented analysis options, such as displaying the individual calls on a map or representing the call volume per square area of interest. Many figures in this thesis have been created by using this graphical analysis environment.

More information about data and the software can be found in Appendix [**D**].

6.1.3 Performance measurement

Performance is measured by the percentage of arrival of CPR, defibrillation, and advanced care within 4, 8 and 12 minutes after the collapse, respectively. As noted in chapter 4, these times represent the maximum limits in which CPR, defibrillation and advanced care should be initiated, to provide acceptable survival probabilities.

These response times are related to an estimated amount of survivors. Unfortunately, the true amount of survivors cannot be assessed. There are three reasons for this. First, the hospitals in the region are forbidden by law to reveal patient data to external parties, unless there are very specific reasons. Many individuals within the University of Groningen and UMCG Ambulancezorg have indicated that it would be extremely difficult to get permission from every hospital in the region within a reasonable amount of time. Second, the survival of an OHCA depends on many factors. Hence, it becomes difficult to assess which change in survival is attributable to which factor. Third, even if all patient data could be obtained, the data collection at the MKNN, UMCG Ambulancezorg, and hospitals contain a considerable amount of errors, which makes any direct conclusion about that data questionable. More information about this can be found in Appendix [**D**].

Fortunately, there is literature available about the relation between response times and the estimated survival probability (review section [**3.7**]). Hence, the amount of survivors is estimated indirectly, by means of the following two logistic parameters:

- the amount of time that has passed since the collapse and the beginning of CPR
- the amount of time that has passed since the collapse and the arrival of the first shock provider. This may be through a volunteer with an AED or an ambulance.

The expression to estimate the survival probability at a given time is as follows:

$$P_{survival}\left(t_{def}\right) = (0.835 - 0.0775 t_0 + 0.0289 t_{CPR}) \\ \times (0.75 - 0.03 t_0 + 0.0167 t_{CPR})$$

$$P_{survival}\left(t_{def}\right) < 0 \rightarrow P_{survival} = 0$$

Here, $P_{survival}(t_{def})$ is the survival probability at the time of defibrillation, t_0 is the time since collapse, and t_{CPR} is the time since CPR was initiated. All times are measured in whole minutes. Details about the creation of this survival function can be found in Appendix [**F**]. A list of all the assumptions is also explicitly formulated in that section.

Hence, the number of survivors for *k* OHCAs is estimated by summing all survival probabilities at the time of defibrillation:

$$E(survivors) = \sum_{1}^{k} P_{survival}\left(t_{def}\right)$$

6.2 Post location strategy

6.2.1 Introduction

Recall that there are three post location strategies: a call hotspot strategy, a main-infrastructure strategy and a risk-based strategy. All those strategies try to minimize the response time, but in different ways. The call-hotspot strategy tries to minimize the overall distance, whereas the risk-based strategy tries to minimize the distance for certain events. Finally, the main-infrastructure strategy tries to maximize travel speeds and thereby achieve better coverage. Therefore, two things need to be known:

- What is the geographical dispersion of calls?
- What is the demand pattern?

6.2.2 Demand: geographical dispersion

The province of Drenthe is a relatively rural area, having a population of about 490.000 people. Just over half of this population (260.000) lives in HEMA: Hoogeveen, Emmen, Meppel, and Assen.

The quality of the infrastructure in Drenthe is good, just like the rest of the Netherlands. However, many roads are curvy as they have been designed like that historically. Therefore, network speeds vary greatly depending on the road track. There is only a limited amount of fast infrastructure in Drenthe, with only two highways available: one north-south (A28) and east-west (A37).

Resuscitation calls occur throughout the entire province of Drenthe. As expected, areas with higher population density also have higher amounts of resuscitation calls: the HEMA-cities are clearly visible in the illustration below.

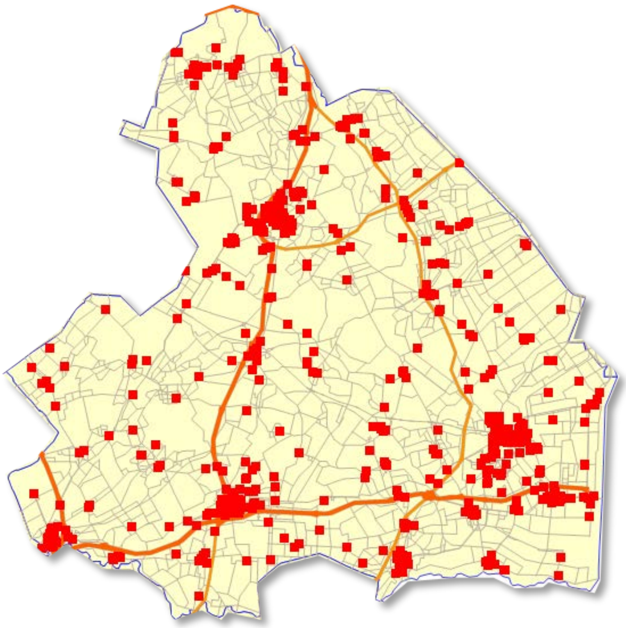

Figure 16: calls for the province in Drenthe (2011+2012)

6.2.3 Demand: patterns and volume

The demand throughout the year is stable, as can be seen in the illustration below, showing the number of calls per four-week period. There appear to be no significant seasonal trends. The total call volume is low, with less than one call each day, as there were 617 calls in two years.

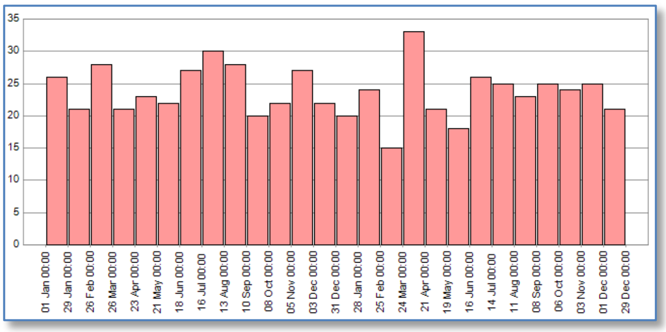

Figure 17: demand of 2011 and 2012, per four-week period.

However, the number of calls throughout the week differs considerably. There are more resuscitation calls on Mondays; also Saturdays and Sundays show an increase. When the data of 2011 and 2012 are evaluated in isolation, they seem quite different as well. However, a T-test showed that the means are not significantly different (see Appendix [**D**]). The difference may therefore be caused by the small size of the dataset (617 calls).

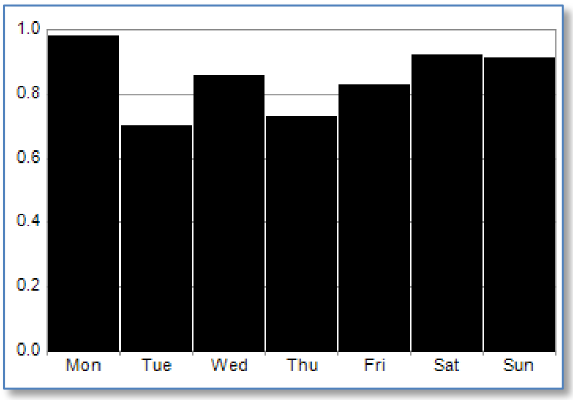

Figure 18: average number of calls per day of the week.

The call volume also differs considerably per hour of the day. The chart below shows that the call volume below midnight and 07:00 hours is much lower than at other times. This is also observable if the data of 2011 and 2012 is evaluated in isolation. There is no valid medical reason why the call volume at night should be lower than during the day. Therefore the cause for the lower call volume at night is probably due to the lower probability of being observed by bystanders. This is not surprising, as it is known that the majority of OHCAs occur at home, so that any bystander (usually a partner) would often be asleep.

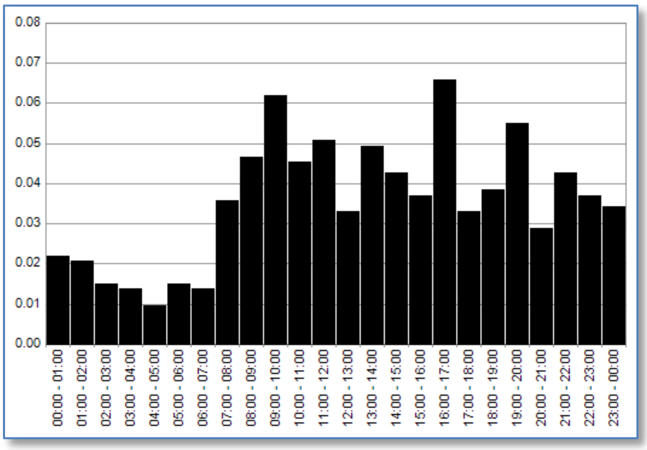

Figure 19: average number of calls per hour of the day.

6.2.4 Current response time distribution

The chart below shows the response time distribution for calls in the years 2011 and 2012:

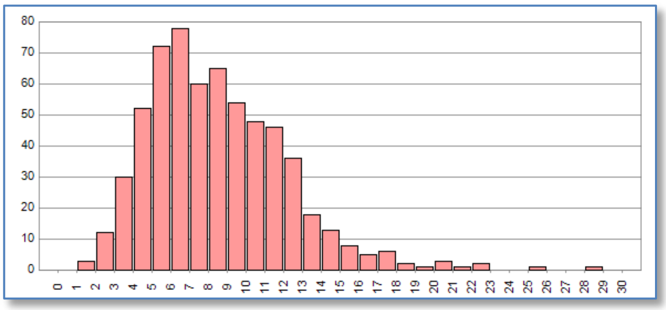

Figure 20: response time distribution for resuscitation calls.

The average response time is 8:26 minutes. The amount of response times within 4, 8, and 12 minutes is 7%, 51% and 86%, respectively. The corresponding estimated survival rate, using the survival function is 11.5%. Note that this survival rate assumes that no specific bystander CPR is given by volunteers. This performance matches with the estimates of physicians and managers within UMCG Ambulancezorg, which estimate crude survival rates until discharge to be 10% - 15%. It should be explicitly noted that they confess that this estimate is a gut feeling, since this data is not collected.

These low survival rates are largely attributable to large response times. In an EMS-only OHCA treatment system, all vehicles would need to arrive within 4 minutes to ensure high survival rates. Unfortunately, only 7% of the vehicles currently manage to arrive within this period.

6.2.5 Impact of call volume on response time

Section [**6.2.3**] showed that that the demand varies throughout the day and week. In determining a good post location strategy, it needs to be known whether the call volume impacts the response time.

It appears that there are no big differences in average response times throughout the week, ranging between 8.8 minutes on Mondays and 8.2 minutes on Sundays, as shown below. There is also no decisive correlation between the average response time and the number of calls: the Pearson correlations have only small and opposite signs for the data from either 2011, 2012 or the total dataset that includes sampling (+0.11, +0.20, and -0.22). Hence, there seems to be no interaction between the call volume and response times per day of the week.

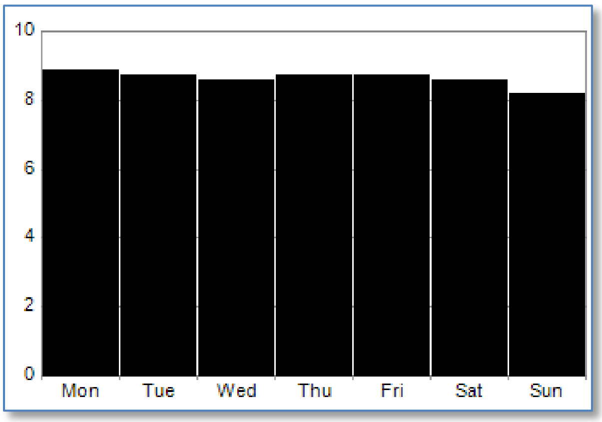

Figure 21: average response times per day of the week.

This is not the case if the response time is evaluated per hour during the day. Response times at night are higher than during the day. Whereas the average during the day is 8 minutes, this is 10 minutes between 23:00 - 08:00 hours.

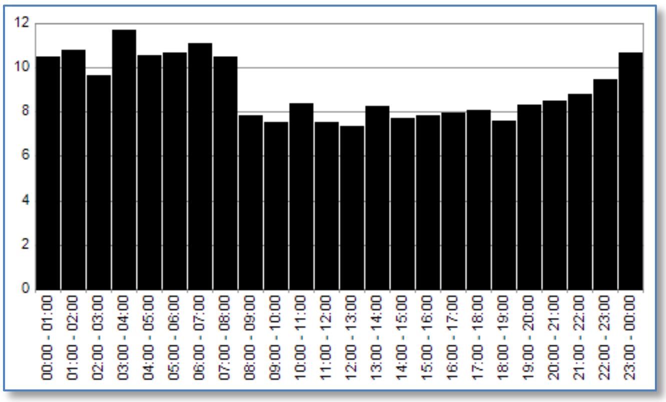

Figure 22: average response time per hour of the day.

There are two possible explanations for this. First, there are more vehicles active during the day. In Drenthe, day shifts usually start at 08:00 and terminate at 17:00 hours. Hence, the coverage outside those hours is poorer, which can result in lower average response times (see also section [**6.5**]). The second explanation for the increased response times is the longer average mobilization time at night hours. This especially explains the strong increase after 23:00 hours: this is the time when staff from evening shifts goes to bed (but remains on duty). Whereas law requires the mobilization time to be shorter than 1 minute during the day, at night a mobilization time up to 2 minutes is allowed. The mobilization times at night are longer, because the sleeping staff needs additional preparation time to get into the ambulance. The chart below shows the component of the response time that is the mobilization time[12]:

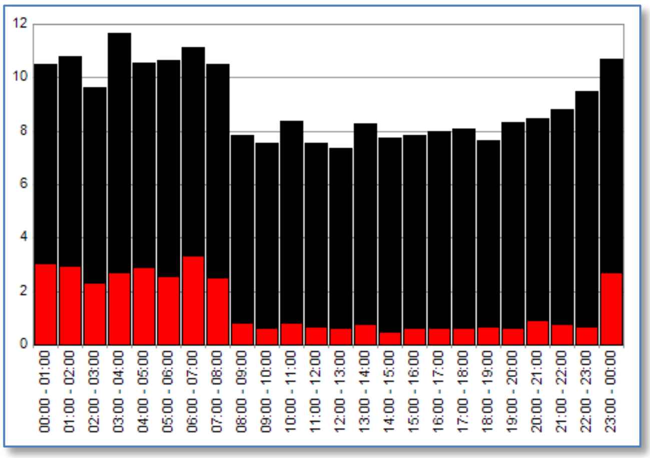

Figure 23: average response time per hour of the day (black), with the average mobilization times also displayed (red).

6.2.6 Implications for post location strategy

The current response time performance is independent of the call volume. This was expected, as the OHCA call volume is low and always prioritized above other calls. This means that call simultaneity has no significant importance. Hence, optimal geographical post dispersion is much more important than geographical coverage for changing call volumes. Hence, for the post location strategy, this means that placing posts adjacent to fast infrastructure is expected to perform worse than aiming for a call hotspot strategy. This is because the latter one minimizes the travel distance for each individual call. Finally, the strong relation between longer mobilization times and the total response time during night hours show that it is important to minimize the mobilization time; it also shows that network speeds at night are comparable with those at daytime. Hence, congestion is less of an issue. This means that response time improvements by using motorcycles will only be minimal.

6.3 Vehicle decisions

6.3.1 Introduction

The second way to increase performance is by making smart vehicle decisions. On a system level it may be single-type system or a tiered system. On a functional level there may be distinguished between emergency vehicles, rapid responders, or transport only. Physically, the vehicles may be land vehicles, water vehicles or air vehicles.

6.3.2 Current performance

Currently, there is a tiered system. This applies to the full vehicle system if all calls are considered; there are ALS vehicles and other types. The nature of OHCA calls and effective use of the Chain of Survival dictates that an EMS provider ultimately needs to arrive with some sort of ALS vehicle to provide advanced care. This is currently also practice in this system and is dictated by law. Therefore, a tiered system will

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[12] The mobilization time displayed here does not include the call time at the control center. The call time, however, is included in the total response time.

perform worse if it leads to poorer dispersion of posts with ALS vehicles as some posts only have other types of vehicles.This is currently not the case in this system: non-ALS vehicles are only added to a post if there is at least one ALS vehicle already situated in it. Review the table in section [**5.3.2**] to see the usual workload distribution of ALS and BLS vehicles and rapid responders.

On a functional level, the use of rapid responders may improve performance if they can profit from eliminated mobilization times. This is because the rapid responders are already prepared and waiting for a call, often outside their initial post. Unfortunately, there is not enough data for OHCA calls only to perform any analysis to. Therefore, the full dataset (containing all A1 priority calls) is used as a reference. For the year 2012, this yields 8325 A1 priority calls. For 7032 of those, the first arriving vehicle was an ALS vehicle, with an average response time of 9:39 minutes. The number of rapid responder responses was much lower, only 763 calls, with an average response time of 8:16 minutes. Although this is considerably shorter, this is not due to the mobilization times: rapid responders were mobilized within 2:39 minutes on average, ALS vehicles within 1:52 minutes. The rapid responders were especially quicker at the scene because they had a convenient location upon the moment of dispatch, reducing the distance and therefore reducing the travel time. Dispatchers at the MKNN confirm that rapid responders are not often dispatched because they think it is only useful if a rapid responder happens to be nearby.

Currently, all vehicles in Drenthe are land vehicles. Water vehicles are not used in daily operations, which would be illogical, as there are no big open waters in Drenthe. There are also no air vehicles in use, even though Drenthe has an airport in Groningen Airport Eelde. However, it is known that air vehicles have mobilization times up to four minutes, which would make it an ineffective way to respond to OHCA calls.

6.4 Staffing

6.4.1 Introduction

Staffing for EMS vehicles can be classified within four levels: first responder, EMT-basic, EMT-intermediate or paramedic. Although the quality of the treatment from EMS personnel can have a huge impact in the survival probability of OHCA victims, the details of procedures is beyond the scope of this thesis, as it is limited to a socio-technical redesign.

6.4.2 Current performance

The high medical demands for OHCAs make it that ultimately always a very skilled professional is required within at most 12 minutes. This is needed, because usually advanced care must be delivered to the patient after defibrillation. Hence, the EMS vehicles responding to OHCA calls will always need to be staffed with a paramedic. Currently this is the case, because all ALS vehicles are manned by a skilled paramedic and a driver, and all OHCA calls are responded to with ALS vehicles. Procedures are currently that the driver will perform the more basic operations, and the skilled paramedic will perform the advanced operations. The current division of tasks should improve the probability of adequate treatment and creates more tranquility at the work place. As noted, this thesis will not cover the exact content of the procedures, as this is beyond the intended scope.

6.5 Control logic

6.4.1 Introduction

As noted in section 5.7, optimal decisions in call queuing, ambulance assignment, add-on mutations and relocations can improve the response time performance. The insights in previous sections in this chapter almost dictate the configuration of the control logic parameters, which is explained below.

6.4.2 Current performance

OHCA calls are treated as a subclass of A1 priority calls, which are currently always given preference above A2 priority and B priority calls. Within all A1 calls, there is no formal rule to prioritize OHCA calls. However, during interviews with control center call takers and dispatchers, they indicate that they are aware that there are hardly any other types of calls that require such an extremely rapid response. The only exceptions to these are traffic incidents and disasters, but these are very rare. In the case of simultaneous A1 priority calls, all the interviewed dispatchers state that they will try to keep both responses within the legal response time limit (15 minutes), unless it is clear that one of the two needs to be responded to as soon as possible, which is the case for an OHCA call.

Although this workflow should generally prioritize OHCA calls, this may not be always the case in practice. This is due to wrong call classification. Using the expertise of a senior policy officer at UMCG Ambulancezorg, historical data were manually analyzed to estimate how many calls are wrongly classified. For the year 2011, it seems that 14% of what should have been OHCA calls are never classified as such. These are often cases that begin with angina pectoris (pain on the chest), which turn into permanent death soon after that. However, the data shows that victims in these cases have never been given heart massage by EMS staff nor has it been classified as a resuscitation attempt. Hence, calls like these may be under prioritized, which may increase response times. Therefore, better call classification is desirable, although it should be noted that the call takers and the dispatchers at the control center are highly dependent on the presence and appropriate actions of bystanders witnessing a (potential) OHCA.

Vehicle assignment for OHCA calls is currently done using the closest-dispatch rule. Section [**6.2**] showed that the response time performance is independent of call volume. That section also showed that the OHCA call volumes are very low. Hence, the only logical vehicle assignment rule is the closest-dispatch rule, which is currently used; the other two coverage rules only make sense if call simultaneity becomes an issue.

All add-on mutations occur occasionally, but only after an intervention by a dispatcher from the control center. Due to the prioritizing protocols just mentioned, mutations for OHCA calls will only be done if it is in favor of the response time of the OHCA call. However, these mutations are very rare and will not be further considered for analysis.

The relocation logic is a hybrid system of real time and multi-period. The real time component aims to maintain coverage of the HEMA cities, the multi-period component adjusts the planned vehicle volume for demand. When comparing the planned vehicle volume with the response time, it seems that the response time increases if the vehicle volume is decreased. However, the decrease is the strongest between 00:00 and 08:00 hours, even though demand in the evening hours (17:00 - 00:00) is comparable to daytime hours. Hence, this reconfirms the statement in section [**6.2**] that the increased mobilization time in the night hours has more impact than the lower vehicle volume. Once again, this was as expected, because the lower vehicle volume is primarily caused by removing duplicate vehicles from larger posts, and call simultaneity is only a minor issue for OHCA calls (review section [**6.1**]).

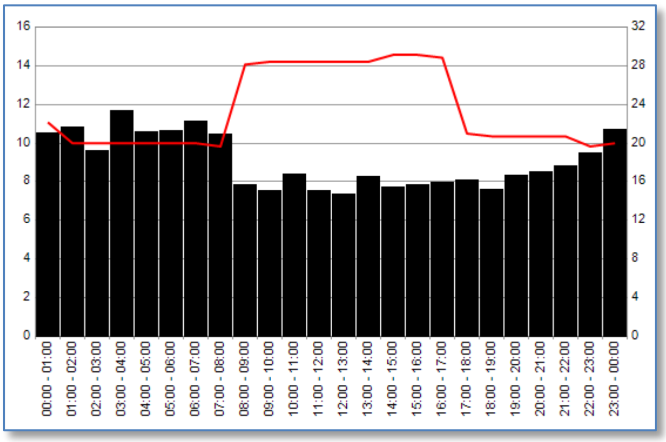

Figure 24: vehicle volume (line) and against response time performance (bars).

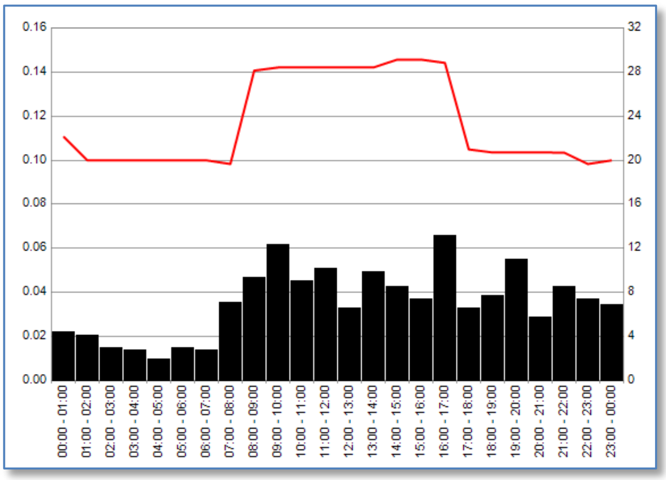

Figure 25: vehicle volume (line) and call volume (bars).

6.6 Rescue services

6.6.1 Introduction

Possible alternative networks that can be considered are those of fire services and the police. As noted in the previous chapter, there are 36 fire services posts, thereby creating a network that is about three times as dense as the 13 ambulance posts. Also, the 14 police posts in Drenthe could help to create a more dense network.

6.6.2 Firefighters response time performance

Currently, the fire services are not being used to respond to resuscitation calls. Hence, there is no information about the current performance of fire services. However, given the relatively dense network of fire services posts, there is a great room for improvement if this network were to be included. Successful examples of a dual EMS and firefighters dispatch system can be found in King County (Gold et al., 2010), Birmingham (Sisiopiku & Cavusoglu, 2012) and Hanover (Toro-Díaz et al., 2013). In these areas, the survival probability of OHCAs considerably increased after implementation of the dual dispatch strategy.

If all parameters besides post density were to be comparable to those of the primary network, the theoretical reduction factor of response times would be equal to its square root. Hence the reduction factor could be as large as square root[13] of (36 fire posts / 13 ambulance posts), which is:

$$\sqrt{(36/13)} = 1.66$$

The average response time consists of 1:33 call taking time, 1:08 mobilization time and 5:56 minutes of driving time. Since 5:56 / 1.66 = 3:34 minutes, the

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[13] As an example: imagine a square, served by one vehicle. Divide the square into four quadrants, which all are given its own vehicle. Observe how this reduces the average expected driving range of √4 = 2.

theoretical average response time could be reduced to 1:33 + 1:08 + 3:34 = 6:15 minutes. Various scenarios that include fire services are tested in chapter 7 (Redesign).

6.6.3 Police response time performance

The police are occasionally used to assist in resuscitation calls. However, staff at the control center is not obliged to alert the police, nor is the police obliged to respond. However, managers at the police indicate that it is common practice for staff at the control center to inform whether a police vehicle is nearby. If this is the case, a police vehicle is usually dispatched, unless it is expected that the ambulance arrives much sooner. However, there is no data available to underpin or debunk this statement. Hence, it is difficult to give a reliable and valid response time performance for the police.

Police vehicles are often stationed at police posts, but its control logic is fundamentally different when compared to current practices for ambulances: a part of the job of police vehicles is to be ‘visible’ in the streets. Hence, police vehicles tend to be driving around a lot. Hence, they could be considered as rapid responders in some cases. Unfortunately, their location is unknown beforehand, making planning very difficult.

Section [**6.3**] showed that the data about rapid responder responses suggest that they are especially convenient due to a fortunate location upon dispatch. However, compared to one single vehicle that is fixed to one location, a vehicle with an unknown position beforehand will increase the average travel distance. This is illustrated in the model[14] below, representing a square area of 2x2 km with a post in the middle. OHCAs are generated randomly in the area. When the vehicle is fixed to its post, the model predicts an average driving distance of 764 meters. However, when the vehicle is positioned randomly within the area, the average driving distance is 1043 meters.

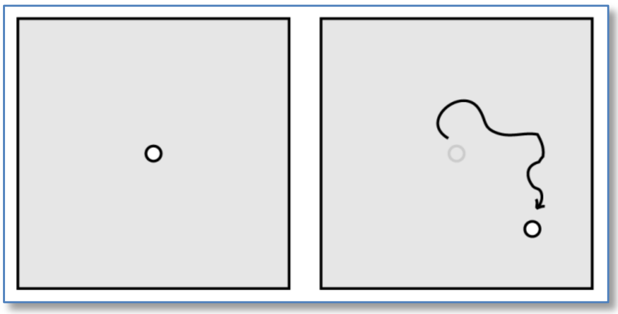

Figure 26: left - the vehicle is tied to the position of the post. Right - the vehicle may be anywhere in the square.

The situation changes when a post has multiple vehicles. This is illustrated below, for the case of three vehicles. Because these vehicles may be anywhere, the coverage suddenly increases, causing the expected travel distance to decrease, compared to the case where all three vehicles are fixed at their post in the middle. The model confirms this hypothesis and predicts an average driving distance 780 meters for 2 vehicles; for three vehicles it predicts 644 meters.

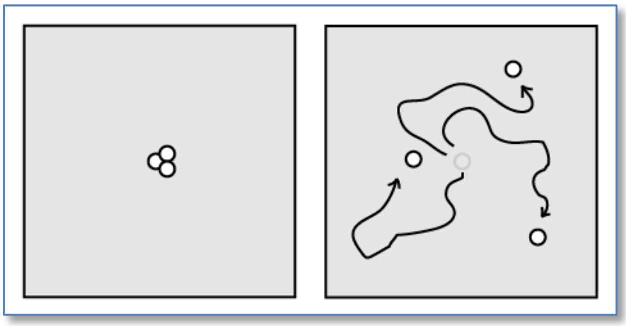

Figure 27: left - three vehicles tied to the position of the post. Right - the three vehicles may be anywhere in the square.

Hence, dispatching police vehicles may be useful, but only because they provide additional vehicles at potentially fortunate locations between the posts, thereby allowing a reduction of travel distances.

6.7 Volunteers

6.7.1 Introduction

The largest database of volunteers for the region of Drenthe is the one from Hartslag voor Nederland, a foundation that aims to strive for better OHCA care. In Drenthe there are around 3360 registered and approved volunteers (December 2013). There is little known about volunteer behavior, as output data is not being collected. Currently, the only known research about detailed volunteer response behavior for OHCA calls in the Netherlands is the promotion research of R. Pijls at the University of Maastricht in the province of Limburg.

6.7.2 Current performance

One of the few things that is known, is which volunteers are alerted and when. This data is collected by the control center. Both the number of alerts and the amount of volunteers per month is increasing through time, as shown in the illustration

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[14] Software: Plant Simulation 10.1. OHCA x and y coordinates are generated with a uniform distribution within the square boundaries. In the right illustration, the vehicle x and y coordinates are generated with a uniform distribution within the square boundaries. 10000 OHCAs have been generated; the confidence plots are shown in Appendix [D].

below.

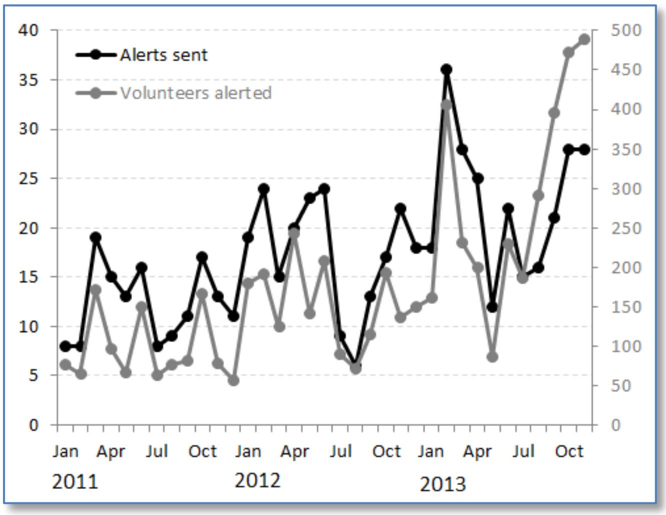

Figure 28: alerts per month (black) and volunteers per month (grey).

Besides input data - which volunteers are alerted - there is not anything known. Data such as the actual amount of volunteers that received the alert, read the alert, responded to the alert, made it to the incident scene, arrival times, etcetera, is not collected.

However, an attempt was made to still assess whether volunteers may have a beneficial impact. As the control center collects data about both volunteer alerts and ambulance data, these could be combined to see whether calls that also had a volunteer alert resulted more often in transport to a hospital: an indication that there is still hope for survival. This was not as straightforward as it seems, as there were a lot of issues with the data (see Appendix [**D**]). For example, only 133 calls in 2011 emerged in both GMS datasets. Even an experienced senior policy officer of UMCG Ambulancezorg could not tell for sure for 15 of those calls whether it was a resuscitation-needy call or not. For the remainder, 65% of the calls was a genuine resuscitation call; the other 35% was a false alert or somebody who passed away considerably sooner.

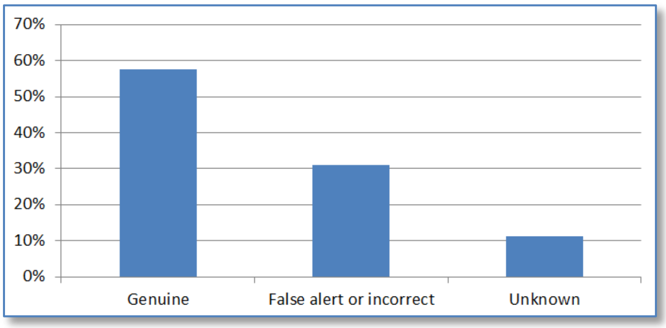

Figure 29: alerts that were genuine resuscitation calls, false, or unknown.

Most of the genuine calls matched with the internal database of UMCG Ambulancezorg. In the cases that volunteers were sent, 68% of the calls had transport to a hospital whereas those without volunteers had transport in 45% of the cases. Therefore, volunteer alerts seem to be correlated with higher probabilities of transport to a hospital. However, a causal relation cannot be underpinned or debunked for this correlation with the current knowledge of the system.

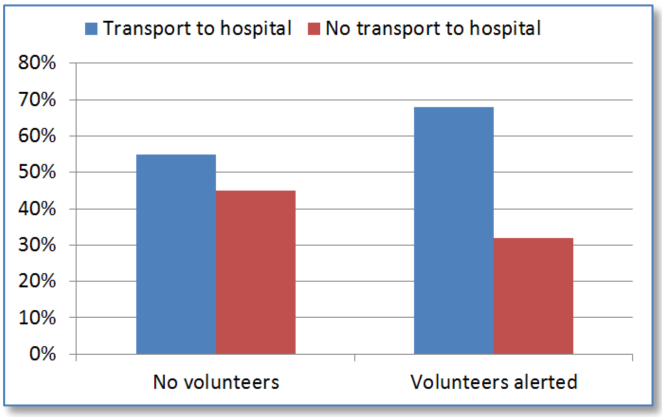

Figure 30: (no) transport to hospital for calls without a volunteer alert and with a volunteer alert.

6.7.3 Volunteer 'post' locations

One feature of the volunteer network is its very high density, compared to the post locations of UMCG Ambulancezorg. Although the actual position of volunteers is unkown, the input addresses in the HartslagNu database may be used to map volunteer densities throughout the province of Drenthe. It is clear that densities vary considerably, as illustrated below

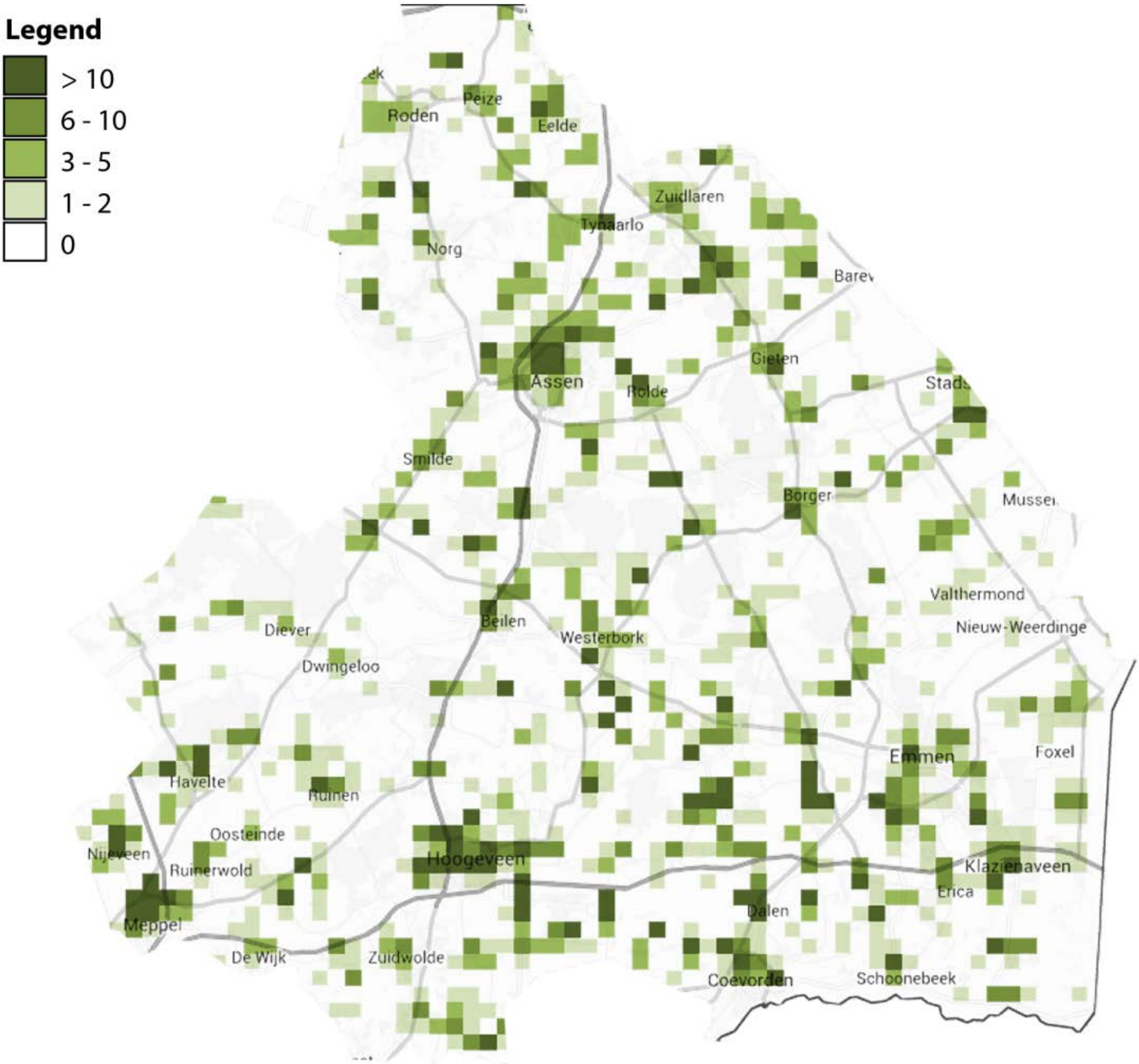

Figure 31: amount of registered and approved volunteers per 1x1 square km in Drenthe. This image was created by grouping all corresponding gps-coordinates of the volunteer-provided addresses upon the moment of registration into 1x1 square km blocks.

In general, volunteer densities tend to be high in city centers. There are also some small communities with high densities, which may be explained by social cohesion. This phenomenon was confirmed by two coordinators of Hartslag voor Nederland. The coverage is good in urban areas. This is not the case for rural areas, where large populations are served by only a few volunteers, which severely reduces the probability of actually having a volunteer at the scene quickly. Within larger cities, the social cohesion may differ from neighborhood to neighborhood, partially explaining the differences within cities. However, it may also be caused by the fact that volunteer associations tend to steer highly on relative population measures: instead of aiming for an absolute number of volunteers, many volunteer associations try to achieve a certain volunteer rate within the population per postal area.

To understand the effects of volunteer density in any area, consider the following model. The model consists of 441 nodes within a grid of 21 x 21 nodes. Each node is given a certain probability of having a volunteer. The nodes are all positioned 100 meters in between. Hence the model represents a square area with a surface of 4.41 km^2.

The middle node (11, 11) is given an OHCA and volunteers are generated throughout the area. Volunteers are responding always and immediately, in a straight line, without mobilization times and with a fixed speed of 7 km/h. The illustration below visualizes this model.

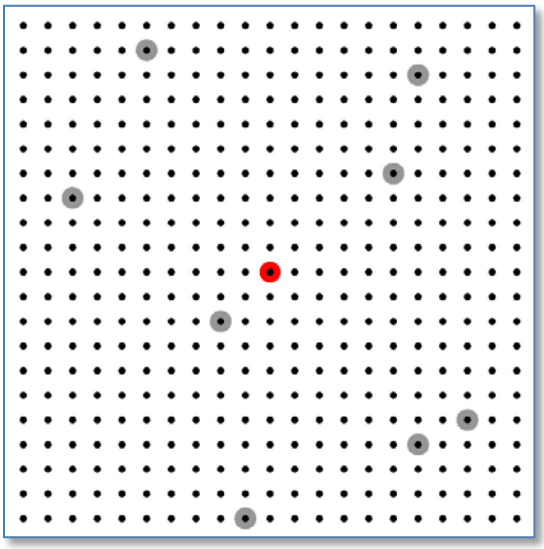

Figure 32: The red center node represents an OHCA, the 8 grey nodes represent volunteers.

The results are shown below. The x-axis shows the probability of a node to have a volunteer created; hence the probability left on the axis (0.064) corresponds with an expected amount of (441 nodes / 4,41 km^2) * 0.064 = 6,4 volunteers/km^2. Note that the x-axis is 2log(x) based.

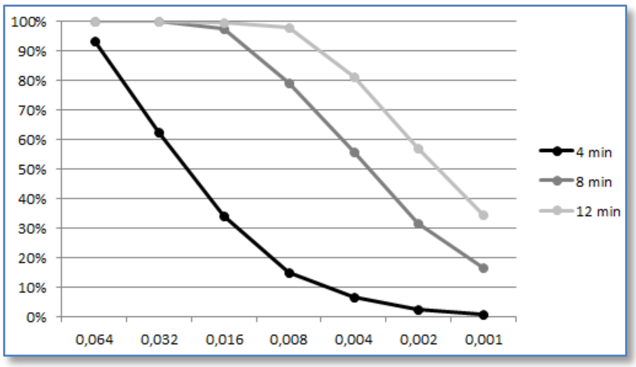

Figure 33: probability of having at least one volunteer in time (4, 8, 12 minutes) for various volunteer densities.

Even though this model assumes that any alerted volunteer will respond, it shows that high volunteer densities are needed to achieve adequate response time performances for short response times. For example: with 1.6 volunteers/km^2 (x-axis at 0.016), only 34% will be at the scene within 4 minutes, but 97% will be at the scene within 8 minutes. The higher the response time threshold, the longer a high performance can be achieved under low volunteer densities.

In reality, volunteers do not always respond. This is due to various reasons: the alert may not have been delivered to the phone, the phone may be turned off, or the volunteer may be somewhere else. This was modeled by giving each generated volunteer a probability of actually responding to an OHCA alert. The illustration below shows 3.2 volunteers/km^2. This corresponds with the density of 0.032 in the previous chart.

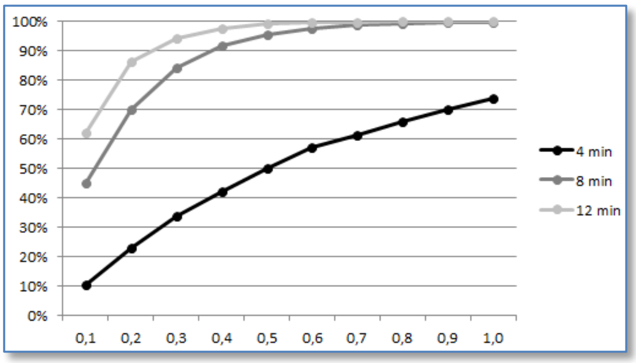

Figure 34: probability of having at least one volunteer in time (y-axis) for three response time limits (4, 8, 12 minute). On the x-axis, the probability of responding is varied between 0.1 - 1.0. The average volunteer density used to create this chart is 3.2 volunteers/km^2.

Lower response probabilities lead to lower performance. However, halving the probability has only minor impact on the 8 and 12 minute thresholds for this volunteer density. Hence, as long as there is another volunteer somewhere else, also able to arrive within the threshold, there is no problem.

To better understand the interaction between density and response probability, consider three scenarios in which there are 5, 3 or 1 volunteers per km^2. Lower densities will perform worse, but are those also more vulnerable when response probabilities decrease? Indeed, as the illustration below shows, the relative decline in performance goes faster if densities are low. This can be explained due to the fact that there is less often another volunteer to make up for the non-responding volunteer.

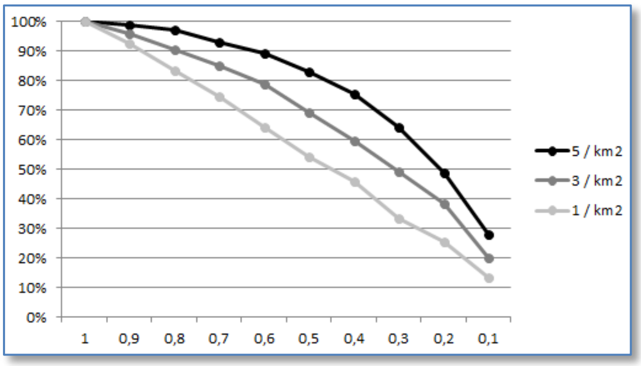

Figure 35: relative probability of having at least one volunteer within some time threshold (5, 3 and 1 volunteer/km2) for various response probabilities.

6.7.4 Implications for volunteer network usage

The previous section has shown that the probability of having a volunteer quickly at the scene is very dependent on density. Very high densities only provide diminishing effects in gain. However, densities lower than 5 volunteers/km^2 start deteriorating performance very quickly for a 4 minute response time threshold, if good response probabilities are assumed. Good response time performance for an 8 minute limit can be achieved up to 2 volunteers/km^2. However, as response probabilities are unknown, especially the 4 minute response time performance may be much poorer.

6.8 AEDs

6.8.1 Introduction

There are about 230 registered and approved AEDs in the province of Drenthe. Similarly as the volunteer usage knowledge, there is little data about AED usage.

6.8.2 Current performance

Only alert data is being collected. The illustration below shows the number of volunteers per month that have been ordered to collect an AED. The strong increase in the last months may be explained by a policy change in which the radius in which volunteers are alerted was increased from 1000 meters to 1500 meters. Unfortunately, there is no data collected whether this change is having any beneficial impact on survival rates in this system.

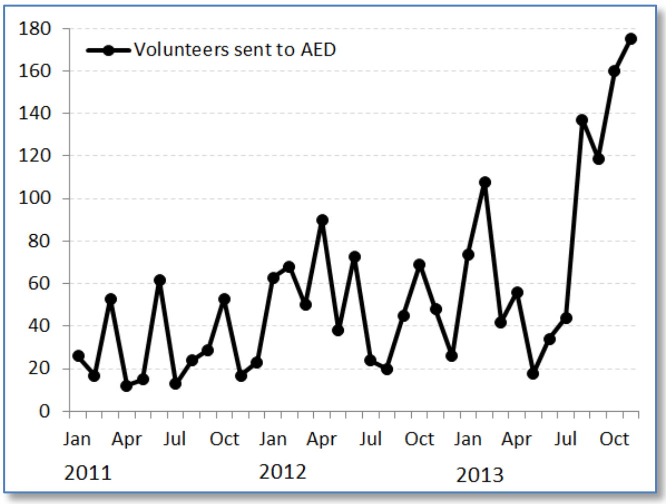

Figure 36: volunteers alerted each month to collect an AED.

6.8.3 AED post locations

Similarly as volunteer densities in section [**6.7.3**], the AED densities have been calculated per 1x1 square. An illustration is shown in the next page. The results show that AED densities are considerably lower than volunteer densities. This may not be unexpected, but in many cases there is zero or only one AED per square kilometer.

This has important implications about the effectivity of the current volunteer and AED network: that it is ineffective. There are too few AEDs within reach for the majority of volunteers. Hence, volunteers are limited to providing CPR only, and need to wait for an additional resource to provide defibrillation and advanced care. As shown in section [**6.2**], EMS vehicles will only arrive within 8 minutes in 51% of the cases to apply defibrillation. Therefore, many volunteer alerts are futile, because the benefits of timely CPR can not be continued with timely defibrillation.

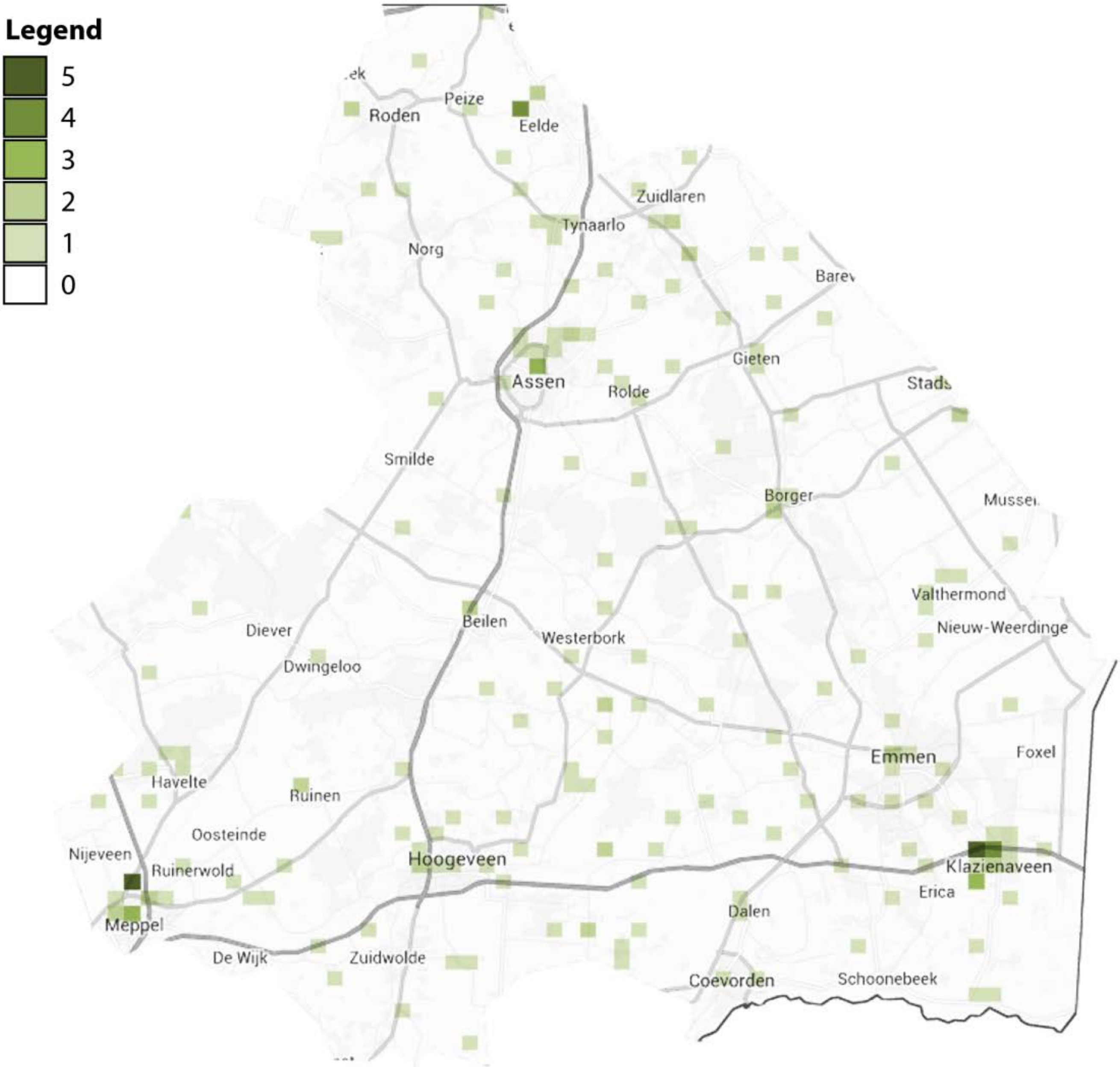

Figure 37: amount of registered and approved AEDs per 1x1 square km in Drenthe. This image was created by grouping the gps-coordinates of the AED addresses upon registration into 1x1 square km blocks.

6.9 Summary

The key insights in this chapter are as follows:

The performance of the EMS network is currently insufficient to ensure good survival probabilities for OHCA victims. Only 7% can be reached within 4 minutes after the collapse, the time in which CPR should begin. Even for defibrillation, which needs to be applied to a victim within 8 minutes, 49% of the calls are not reached in time. Advanced care, needed within 12 minutes, is at the scene in 86% of the calls. Using the survival rate formula, the expected survival rate of the EMS-only system is 11%.

It seems futile to strive for an EMS-only solution for good OHCA treatment. The post densities would need to be considerably higher, which would imply very high investment and operating costs. Here, the benefits of the existing firefighter posts or volunteer locations can be exploited, because these already have much higher densities.

Although there are too few post locations in the EMS system to adequately respond to OHCA calls, there are no significant flaws in other elements that could contribute to a quick response time. All posts are equipped with vehicles to serve OHCA calls, the staff is skilled and the control logic is set-up correctly to quickly respond to OHCA calls. Hence, any significant improvement can only be achieved by striving for higher post densities and giving supplementary networks more control. The supplementary networks that have been considered are those of the police, firefighters, volunteers and AEDs.

The firefighter network has a post density that is almost three times as high as that of the EMS network. However, it is also characterized by slower mobilization times, because it is largely operated by volunteers that have occupations elsewhere when a call is received.

The police network may also be a useful addition, but this network is highly unreliable due to unknown availability and vehicle locations beforehand. However, its main advantage is that occasionally vehicles may be positioned at a very favorable location, thereby reducing the response time.

The volunteer coverage is good in many urban areas, as well as on specific rural communities. However, most of the area in Drenthe has a coverage that is too low to provide high probabilities of a quick volunteer response. However, this adequate volunteer network coverage is only applicable for providing CPR, because the AED network is still underdeveloped. Hence, the next step in the Chain of Survival, defibrillation, cannot be executed properly by volunteer networks currently. Since EMS vehicles will also arrive too late for defibrillation very often, this makes further treatment futile. This should be considered a waste, because advanced care and transportation, the final steps in the Chain of Survival can be initiated in time by EMS providers much more often (86% within 12 minutes).

Many elements that could allow effective OHCA treatment are already available: there is a skilled EMS provider (UMCG Ambulancezorg) that tries to make data-driven decisions, adequate non-congested infrastructure, an increasing volunteer database with semi-automated alert system, and supplementary unused networks. However, these elements are not properly cooperating to allow effective treatment of OHCA victims. One other major flaw in the current treatment is that there are too few resources that could deliver the function of defibrillation to the OHCA victim. Hence, a redesign needs to address these issues to improve timely interventions and increase the survival probability.

7. System redesign

7.1 Introduction

7.1.1 Approach and chapter structure

The previous chapter showed some requirements for the redesign. Two important requirements are that improvements need to be done on multiple networks, and that additional resources are required to execute the defibrillation step adequately. However, looking for configurations of multiple networks and with additional resources means that the problem space becomes large very quickly. Hence, the redesigning needs to be done in a structured fashion.

The redesign will be done in two steps. The first step is a crude redesign in section [**7.2**] for the different networks in isolation. It maps the response time ranges per network in which a redesign should aim for. As will be shown, the EMS network should at least be designed for a 12 minute response time limit, the rescue services and AED networks for an 8 minute response time limit, and the volunteer network for a 4 minutes response time limit. The second step is a more detailed redesign for each of the individual networks.

This second step uses the three steps in the Chain of Survival for guidance. This means that section [**7.3**] will redesign for timely CPR, section [**7.4**] for timely defibrillation and section [**7.5**] for timely ALS. The networks in these sections are evaluated in isolation. After redesign suggestions for the individual networks in these sections, the final step is to test performance for hybrid networks, which is done in section [**7.6**]. A network is considered hybrid when more than one network works together with another one, such as the EMS network together with the firefighters' network. Finally, section [**7.7**] presents the final redesign proposal, based on the findings in the earlier sections in Chapter 6 and this chapter.

7.1.2 Redesign techniques and analysis

The crude effect of any change is first calculated with 'hard' formulas using spreadsheet software, where possible. For example, the crude coverage of posts can be calculated straightforward using simple area formulas.

After determining the crude parameters, a design is implemented in the GIS simulation software Optima Predict. This software was also presented in section [**6.1.2**] where its built-in data analysis tools were used to analyze input data. However, it also has a powerful simulation engine, dedicated to simulate the response of vehicles for demand points over a road network. The road network speeds are tuned per link, and are calculated by averaging historical average vehicle speeds on those links. The OHCA calls are extracted from historical data, collected by UMCG Ambulancezorg. A more detailed explanation about the software and data can be found in Appendix [**D**].

Similar as in the analysis chapter, the results are analyzed using the data analysis toolkit in Optima Predict and translated to survival rates using the survival probability formula, which was constructed in Excel. This survival probability formula is also explained in detail in Appendix [**F**].

An overview of all scenario results in this chapter can be found in Appendix [**G**].

7.2 Crude redesign

7.2.1 Primary network

Chapter 6 showed that moving or adding posts are the most viable options to increase responsiveness for the primary network. To further specify the range of redesign options for the primary network, consider the following reasoning: the two figures below illustrate the current theoretical coverage under the legal 15 minute response time (13.5 minutes of drive time[15]). As it can be seen, three posts would be very insufficient for coverage. However, coverage becomes reasonable if six posts would be conveniently located. The green roads are areas that can be reached within the 15 minutes, the black ones cannot. The coverage areas have been calculated by using the historical ambulance speed data per road link (see Appendix [**F**]).

Figure 38: coverage of 3 stations (left) and 6 station (right) within 13.5 minutes of driving.

Since Drenthe is 2980 km^2, each of the six posts covers about 447 km^2. If circular radiuses are assumed, with uniform and constant driving speeds, this relates to an average speed of 53 km/h[16]. For Drenthe, the relation between the number of posts required to achieve full coverage under any response time requirement is then as follows:

---

[15] The current crude average of call time and mobilization time during daytime is 1.5 minutes.

[16] Because 2980/6 = 447; 447/π = 142; √142 = 11.93; (11.93/13.5) * 60 = 53.

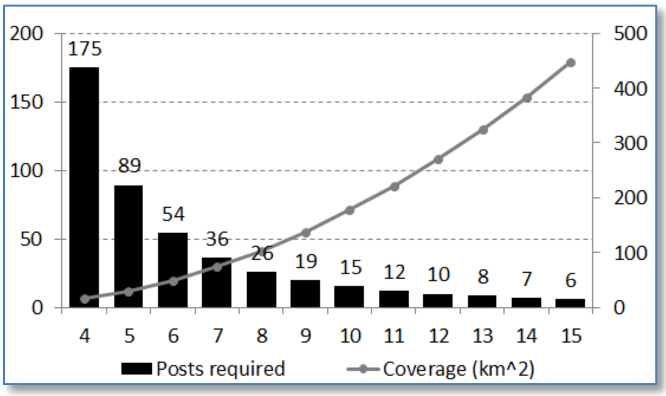

Figure 39: relation between the response time requirement (x-axis) and number of posts required for Drenthe (bars, left axis). The line indicates the coverage per post (in km^2, right axis).

The bar on the right end of the chart depicts the situation mentioned just earlier (15 minutes response time, 6 posts, 447 km^2 coverage per post). Hence, the theoretical required number of posts can be read from this chart:

- CPR, 4 minutes: 175 posts
- Defibrillation, 8 minutes: 26 posts
- Advanced care, 12 minutes: 10 posts

Since any additional fully operated 24-hour shift post costs about 700.000 euro, the additional expenses for maintaining a 4, 8 and 12 minute response time coverage policy would be 118.3, 14.0 and 2.8 million euros, respectively. Given the amount of costs involved, it is infeasible to attempt any serious redesign for a 4 or 8 minute response time limit. Hence, the primary network should only be adjusted to comply to the requirements of the last step in the Chain of Survival, which is to provide advanced life support within 12 minutes.

7.2.2 Rescue services

Using the same chart as in the previous section, the firefighters are expected to have significant better coverage than the EMS network. This is because the chart predicts that 36 posts can cover areas within a 7 minute response time limit. Hence, the current 36 posts of the firefighters network could be well used to provide the function of defibrillation, which needs to be done within 8 minutes.

The police have the posts stationed at similar places as the EMS network. However, the availability, location, and mobilization time of police vehicles is highly unpredictable beforehand. As police officers cannot provide advanced care, they would also need to arrive within 8 minutes and provide the defibrillation function. Hence, the number of responding nodes, in this case driving vehicles, would need to be similar to the number of firefighter posts to achieve adequate coverage. This means that there should be about 36 police vehicles ideally dispersed in the province of Drenthe. This is rather unlikely; hence the police vehicles are expected to be a poor addition in the Chain of Survival. Nevertheless, some configurations will be simulated later in this chapter.

7.2.3 Volunteers and AEDs

The chart in section [**7.2.1**] cannot be used to provide estimations for the number of volunteers required. Therefore, another approach was used: a typical urban scenario was created, using the road network and volunteer location data of Assen. In a baseline scenario, volunteers moved at 8 km/h (jogging) and were set to always respond to an alert after one minute of mobilization time. This led to a baseline performance of 36% at the 4 minute level (CPR), and 93% at the 8 minute level (defibrillation). This is much better than what would be possible than with the EMS network or any of the rescue services. Hence, the volunteer network will be redesigned to achieve reasonable response time performance for the most time-critical step in the Chain of Survival: to provide CPR within 4 minutes.

Similarly, the AED network of Assen and its road network was used to create a baseline scenario for AED scenarios. As AEDs are more scarce, the baseline scenario assumes that volunteers try to move faster to collect it, by quickly collecting a bicycle. Hence, the baseline scenario assumes double travel speeds (16 km/h), comparable to biking speed. Still, the baseline performance for AEDs was still only 26% for 4 minutes; 87% arrived within 8 minutes. Hence, the AED network will first be redesigned to have a better response time performance at 8 minutes. This is the upper limit in which defibrillation should be provided to any OHCA victim, at least when CPR was initiated timely enough.

7.2.4 Crude redesign results

This section narrowed the possible search space by defining purposes per individual network: to have a reasonable response time performance to adequately perform the function of providing CPR, defibrillation or advanced care. A summary is provided here:

- CPR (4 minutes): volunteer network.
- Defibrillation (8 minutes): First AED network and firefighter network. Otherwise: police network.
- Advanced Care (12 minutes): EMS network.

7.3 Redesign for timely CPR

7.3.1 Introduction

The only network that is capable of achieving good response time performance at the 4-minute level is the volunteer network. It was attempted to do a full scale simulation of Drenthe in Optima Predict, using the 3360 registered volunteers in the HartslagNu data. However, the simulations increase exponentially in time and computational power as a function of the number of nodes (volunteers). Unfortunately, this made any simulation with more than several hundreds of nodes infeasible. Alternate simulation packages have been sought, but none have been found that seemed to be usable for this purpose. Hence, a small scale approach was used.

7.3.2 Volunteer network

This approach involves using only a small geographical region: the city of Assen, its road network, registered volunteers and historical OHCA call data of 2011 and 2012. The locations of the registered volunteers are shown below. The image below was taken from the graphical simulation environment in Optima Predict.

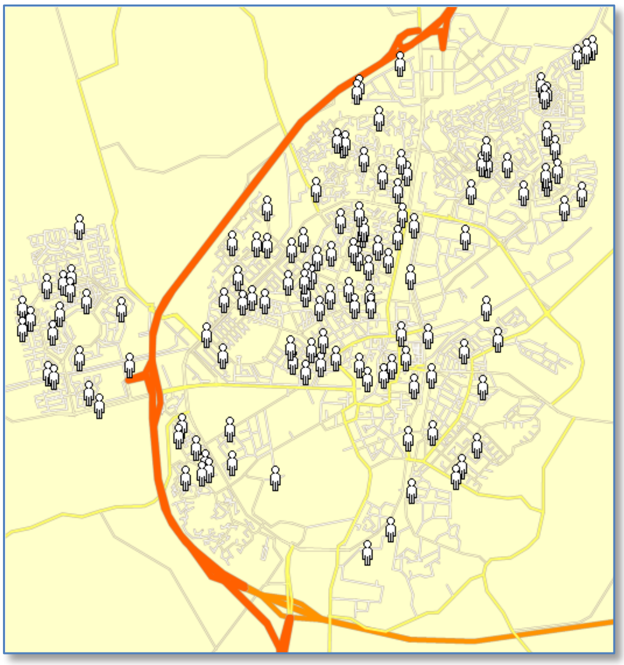

Figure 40: registered and approved volunteers in Assen (HartslagNu database, december 2013).

The baseline scenario was executed, using the following assumptions about volunteers:

- they run towards a resuscitation call (8 km/h)
- they always respond
- they begin moving after 1 minute (fixed value)

The following variations to this baseline were applied for sensitivity analysis:

- Decrease volunteer density to 50% (average the results of 2 scenarios, in which either the even and uneven volunteer entries were removed).
- Decrease density to 25% (average the result of 4 scenarios, in which the 1st, 2nd, 3rd, or 4th volunteer entry was not removed)
- All earlier scenarios, using double speeds (16 km/h).

The results are shown in the table below. Two things are noticeable. First, when moving with double speed, a volunteer density of 25% compared to the baseline scenario is sufficient to maintain similar performance (01a versus 02c). Note that an overview of all scenario results in this chapter can also be found in Appendix [**G**].

Response time performance	4 min	8 min	12 min
01a. Baseline	36%	93%	100%
01b. 50% density	21%	86%	99%
01c. 25% density	11%	68%	95%
02a. Baseline, speed 2x	70%	100%	100%
02b. 50% dens, speed 2x	49%	99%	100%
02c. 25% dens, speed 2x	34%	97%	100%

Table 6: response time performance results.

The specific benefits of the provided CPR are dependent on the moment of defibrillation, which is unknown for these scenarios. However, the gain can still be quantified by setting a fixed defibrillation time for all victims. Since the survival rate formula without CPR predicts that there are no survivors after 12 minutes (for an example see Appendix [**F**]), any survivors at 12 minutes are fully attributable to any CPR given before that time. If the CPR would be provided from the moment the first volunteer arrives, up to the moment of the fixed defibrillation time of 12 minutes, the survival rates would be as follows:

Survival rates	Survival if $t_{def} = 12$
01a. Baseline	16.4%
01b. 50% density	14.0%
01c. 25% density	11.1%
02a. Baseline, speed 2x	20.2%
02b. 50% dens, speed 2x	18.9%
02c. 25% dens, speed 2x	17.1%

Table 7: survival rates if CPR would continuously be given since volunteer arrival, and defibrillation occurs 12 minutes after the collapse.

The performance results of these scenarios are expected, as the behavior matches with the analytical exploration model in section [**6.7.3**]. It stresses that good response time performance at the 12 and 8 minute level is rather easy to achieve, whereas good performance at the 4 minute level requires either high volunteer densities, or high response probabilities, given the fact that travel speeds are rather slow. For example, the baseline scenario (01a) has a high volunteer density of approximately 4.5 volunteers per square km, and always a 100% response probability. Still, it performs only poor, which can be explained due to a non-uniform distribution of volunteers (compare the two figures below). This stresses the importance of having a good geographical dispersion, assuming very low network speeds. This becomes less important if speeds would increase (scenario 02b and 02c).

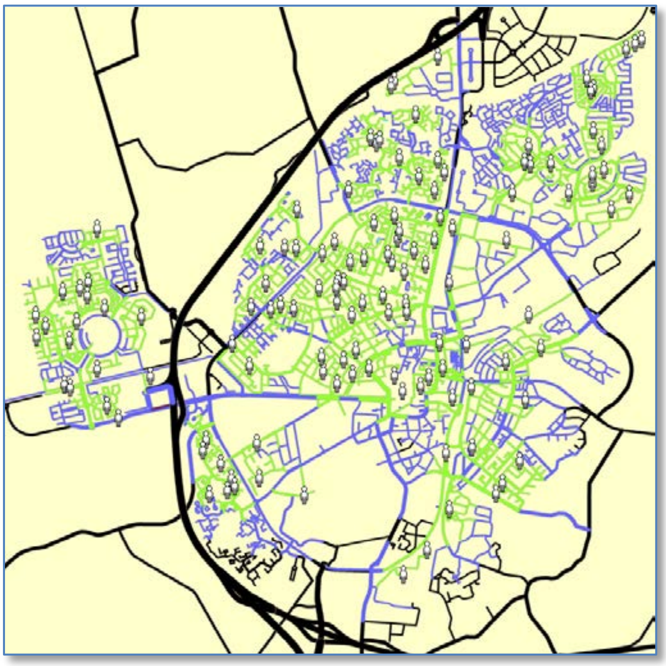

Figure 41: the green areas indicate 4-minute coverage, blue 8-minute coverage. This image is the configuration in scenario 01a.

Figure 42: the green areas indicate 4-minute coverage, blue 8-minute coverage. This image is one of the configurations that are part of scenario 02c. Note how a doubling of travel speeds reduces the urgency of having 100% response probability: in this case, a 25% response probability still gives reasonable coverage.

7.4 Redesign for timely defibrillation

7.4.1 Introduction

As summarized in section [**7.2.4**], adequate defibrillation response time performance (8 minutes) is possible using the AED network and fire fighters network. The AED network can be used by volunteers to defibrillate OHCA victims; the fire fighters network can also be used to respond to calls in more rural areas as they have service vehicles at their disposal. Finally, the police network is considered, although the crude redesign suggests that this network will have a poor 8 minute response time performance.

7.4.2 AED network

The first network that will be tested in this section is the AED network. A baseline scenario was constructed, using the following assumptions:

- A nearby volunteer is immediately available
- AEDs are moved with 8 km/h
- 1 minute of mobilization time (fixed)

The following variations to this baseline scenario were applied for sensitivity analysis:

- 2 minutes of mobilization time (longer searching)
- Density increase of AEDs with 50%. The additional AEDs are placed at intuitive places that lack coverage.
- Density increase of AEDs with 100% (double density). The additional AEDs are placed at intuitive places that lack coverage.
- Some scenarios using double speeds (16 km/h)

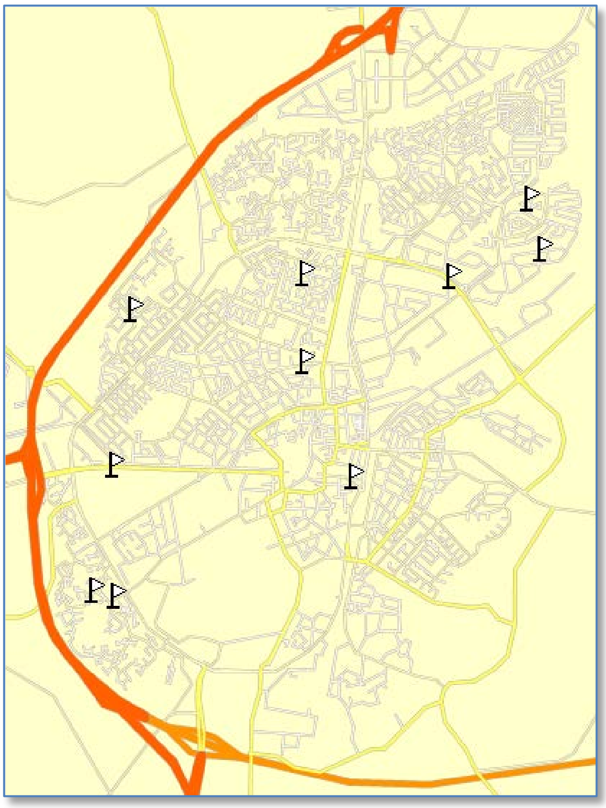

Figure 43: AED baseline locations in Assen (HartslagNu database, december 2013)

The results are shown below. The survival rates are calculated using the survival function of section [**6.1.3**]. In this case, the OHCA victim is assumed to remain alive after defibrillation, since this scenario does not include ALS from an EMS provider afterwards. Note that this scenario assumes that no CPR was given before defibrillation.

	4 min	8 min	12 min	survival
10a. Baseline	6%	28%	68%	7.0%
10b. Baseline, t_{mob} +1	1%	22%	57%	4.9%
11a. Speed x2	17%	81%	94%	18.2%
11b. Speed x2, t_{mob} + 1	6%	67%	94%	13.6%
12a. Density +50%	9%	45%	94%	10.3%
12b. Den+50%, t_{mob}+1	3%	30%	84%	7.2%
13a. Double density	10%	54%	96%	11.9%
13b. Double d, t_{mob}+1	3%	36%	87%	8.3%
14a. Double d, speed x2	29%	97%	100%	24.4%
14b. Double d, x2, t_{mob}+1	10%	94%	100%	18.9%

Table 8: performance results for AED network scenarios.

The results show that a large increase in survival rates can be achieved in urban settings, by effectively using AEDs. Especially when AEDs are transported with bike speeds instead of running, the gain is large. However, big improvements can also be made by investing in additional AEDs. It is no surprise that a combination of double speed and double density yields the best results (14a). The results remain high if an additional minute of searching is assumed (14b). Installing additional AEDs is a low-cost solution, as one AED will cost about 1500 euros to install. For the case of Assen, a doubling of AEDs implies an investment of 15000 euros, as there are currently 10 registered AEDs.

7.4.3 Fire fighters network

Currently, the network of fire fighters is not used. As the network is much denser (36 posts) than the EMS network (12 posts), it seems a promising network that can be used to treat OHCAs more effectively. As noted earlier this chapter, it is probably feasible to use firefighters for defibrillation, as the expected coverage range in this network density is about 8 minutes.

A baseline scenario was constructed, using the following assumptions:

- Fire fighters are always alerted and are always responding to calls.
- They have service vehicles right at their disposal.
- Travel speeds equal the travel speeds of ambulances for medium priority calls (A2 calls), because the service vehicles are not priority vehicles.
- An AED is located in each service vehicle. Hence, the arrival of a fire fighter equals the moment of defibrillation.
- Mobilization time patterns are equal to those of vehicles at UMCG Ambulancezorg.

The following variations to the baseline scenario have been applied for sensitivity analysis:

- The mobilization time is 4-6 minutes (uniform distribution). This mobilization time is current practice for firefighting calls, in which a fire truck must be collected at the barracks and clothes need to be changed. Hence, this scenario assumes that AEDs are only available in fire trucks or barracks, and that laws require firefighting volunteers to be in these specific vehicles when responding to calls.
- The mobilization time is 2-4 minutes. In this scenario, it is assumed that no changing of clothes is required. However, firefighting volunteers still need to collect the AED at the barracks.
- Travel speeds equal the travel speeds of ambulances driving to high priority calls (A1 calls).

The results are shown below.

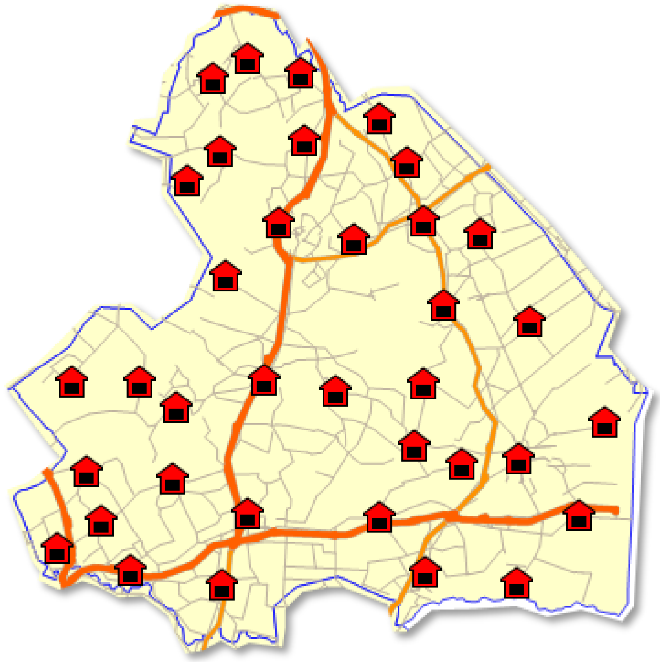

Figure 44: location of the firefighter posts.

	4 min	8 min	12 min	survival
20a. Baseline	13%	67%	94%	10.7%
20b. 4-6 mobilization	0%	7%	50%	1.7%
20c. 2-4 mobilization	0%	26%	70%	5.2%
20d. A1 speeds	13%	66%	94%	15.2%

Table 9: performance results for firefighter scenarios.

Once again, the results assume that no CPR was given by external providers before arrival of the vehicle. The results show that using fire services can be a good addition in the Chain of Survival for out-of-hospital-cardiac arrests. To be effective, firefighters need to be able to start driving with comparable mobilization times as EMS vehicle currently do. If they are also allowed to exceed regular speed limits in comparable ways EMS vehicles can for high priority calls, the estimated survival rates increase to 15.2%. This is better than the baseline performance for the EMS network, predicting a survival rate of 11.5% (compare with scenario 40a). This difference in performance is fully attributable to the tripled density of posts.

7.4.4 Police network

Estimating and modeling police vehicle patterns is difficult, as the vehicles are usually patrolling. This is a fundamental difference compared to EMS vehicles and fire services vehicles, which can be modeled as waiting stationary at a post. Because police vehicle location patterns are unknown, the system is modeled by using actual posts and an equal amount of ‘ghost’ posts, assigned at various locations between posts to create geographical coverage without knowledge of where calls occur. Next, all posts are assumed to have exactly one vehicle which may respond; because it’s location is supposed to be unknown beforehand, a large mobilization time (uniform 0-8 minutes) is used to model this.

The following variations to this baseline scenario have also been tested:

- Mobilization times of 0-6 minutes (uniform).
- Mobilization times of 0-4 minutes (uniform).
- No ‘ghost’ posts - only the official police posts.

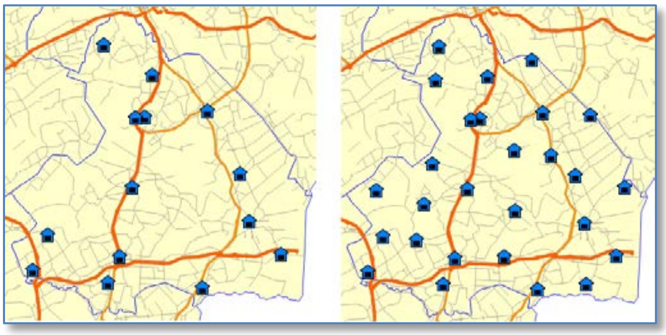

Table 10: police posts as in reality (left). Dummy police posts added to model randomly located vehicles (right).

	4 min	8 min	12 min	survival
30a. Baseline	4%	34%	77%	7.9%
30b. 0-6 minutes	6%	45%	83%	9.9%
30c. 0-4 minutes	10%	55%	88%	12.8%
30d. No ghost posts	4%	55%	88%	6.6%

Table 11: results from several scenarios with different mobilization times.

The results show that using the police network can also be a good way to increase responsiveness. Although the results are not as good as compared to using the firefighter with quick mobilization times, they are still often quickly at the scene. This is only the case if police vehicles are indeed often very dispersed through the region (as modeled with ghost posts); otherwise the advantages will be minimal, because the posts locations are similar to those of the EMS network.

7.5 Redesign for timely ALS

7.5.1 Introduction

The only network capable of providing ALS is the EMS network, due to the high demands of the care provided. Hence, this network is the only network considered for redesign in this section.

7.5.2 Current baseline scenario

The baseline scenario for the EMS system has the following properties:

- The post locations of the situation as early 2013 are used.
- Each post always has a vehicle available. This is because OHCA calls are prioritized above all other A2 and B priority calls and also most of the A1 calls.
- Travel speeds are derived from known average network speeds for high priority calls. These speeds are known per individual road link. More information is available in Appendix [**F**].
- Mobilization times are modeled using historical data and vary between daytime and night. More information is available in Appendix [**F**].

The results for the baseline scenario, which represent the current practices of the OHCA treatment flow, are as follows:

	4 min	8 min	12 min	survival
40a. Baseline	7%	51%	86%	11.5%

Figure 45: results of the baseline EMS network. This represents current practices of the EMS provider in Drenthe.

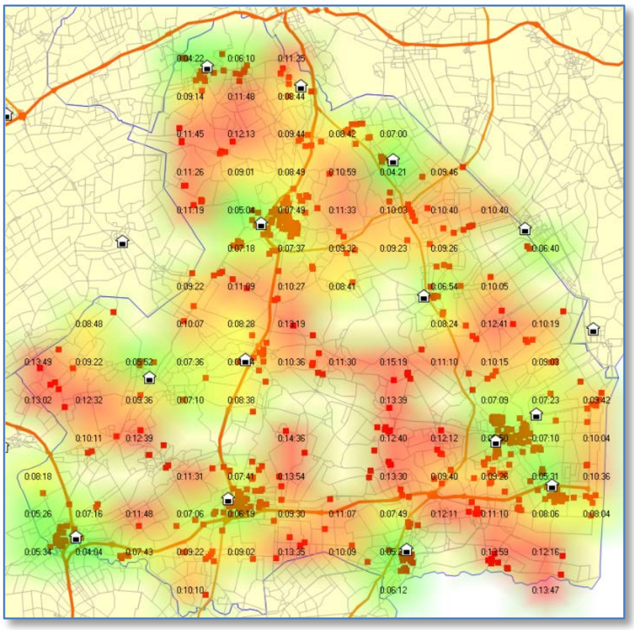

Figure 46: response times of baseline scenario. Red areas indicate response times longer than 12 minutes.

As the illustration above shows, the current post location system fits a ‘call hotspot’ location system.

The only exception is central Drenthe. However, during the execution of this thesis, a new post was located exactly at that place (near Westerbork) to resolve this issue. It also fits a risk-based location system, as 9 out of the 10 biggest cities in Drenthe have a post. However, the match with a fast-infrastructure location system is mediocre. More about the post location matches can be found in Appendix [**C**]. To summarize, the post location system matches as follows:

- Call hotspot: very good
- Risk-based (population): 9/10 cities covered
- Highway proximity: 5/13 posts within 200m
- Major road proximity: 13/13 posts within 1000m

7.5.3 Increasing region-wide performance

Adding posts

Chapter [**6**] showed that it is better to attempt performance increments by adding posts as close as possible to as many as possible calls. Hence, by adding posts near high volumes (call hotspot match) in red areas, the performance gain should be most noticeable. Three areas are noticeable: southwest Drenthe (Havelte), central Drenthe (Westerbork) and southeast Drenthe (Schoonebeek). Hence, the following variations of the baseline scenario have been simulated:

- Add 1 post (Havelte)
- Add 1 post (Westerbork)
- Add 1 post (Schoonebeek)
- Add all three posts (Havelte, Westerbork, Schoonebeek)

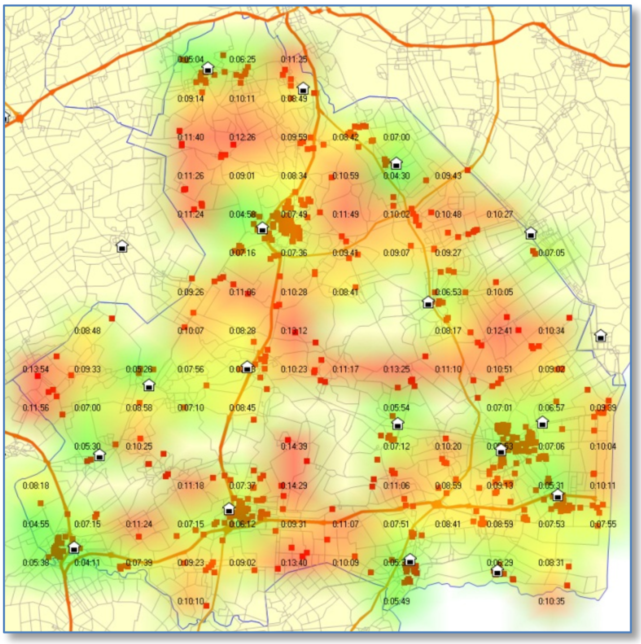

Figure 47: three additional posts in Havelte, Westerbork and Schoonebeek yield better results.

In the new scenarios, the response times improve. An overview of the results is shown below, showing that a new post in Schoonebeek is the best contributor to faster response times. However, the gain only becomes truly significant if all three posts are added. However, the gain in that case (+1%) is disappointing, but it was expected due to the crude redesign of the EMS network in section [**7.2.1**]. As found in section [**7.4.3**], even a large increase in posts from 13 to 36 will only give an estimated survival gain of 3.7% (from 11.5% to 15.2%).

	4 min	8 min	12 min	survival
40a. Baseline	7%	51%	86%	11.5%
40b. + Havelte	7%	51%	86%	11.6%
40c. + Westerbork	7%	53%	86%	11.8%
40d. + Schoonebeek	8%	53%	87%	11.9%.
40e. + All three	9%	55%	89%	12.5%

Table 12: response time performance and estimated survival rates for several scenarios.

Adjusted travel speeds

Some other variations to the baseline scenario have also been tested:

- Using a rapid-responder system for ALS; this is simulated by increasing all network speeds by 20%.
- A dedicated highway network parallel to existing highways and major thoroughfares; the network speeds are 200% here. The image below illustrates which network parts have been upgraded.
- Use three aircrafts, instead of the current ambulance vehicles. The speeds were set to a fixed 200 km/h. The mobilization time was set to 4 minutes, comparable with current MMT dispatches.

Figure 48: Drenthe with road network edits. The thick red roads have double network speeds, to simulate dedicated infrastructure for emergency services.

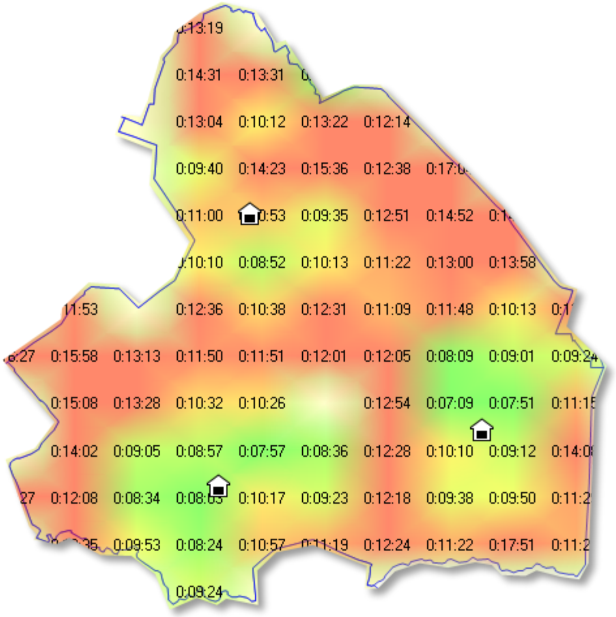

Figure 49: aircraft simulation and response times. Network speeds: 200 km/h, 3 aircrafts in Assen, Hoogeveen and Emmen with 4 minutes mobilisation time.

	4 min	8 min	12 min	survival
40f. All roads 120%	11%	61%	93%	14.0%
40g. Major roads 200%	8%	55%	88%	12.4%
40h. Three aircrafts	0%	31%	72%	5.3%

Table 13: results for scenarios with network speed edits.

The results show that dedicated high-speed infrastructure hardly contributes to faster response times or survival rates (scenario 40g). A rapid-responder-only vehicle system, traveling 20% faster than current vehicles, would contribute much more. However, this solution might present some legal issues due to work safety issues, considering the higher traffic injury risks and weather-related issues. Using only air vehicles is also infeasible. The high mobilization time causes very low survival rates, because most of the gain needs to come in the first four minutes. Also, all of these latter variations are very costly, while the gain is minimal. Using the existing networks of volunteer, firefighters and police is much cheaper and therefore preferable.

7.5.4 Increasing local performances

The poor performance increments in section [**7.5.3**] under scenarios 40b to 40e, suggest that the addition of these posts is still non-optimal. As survival increments are most noticeable in the first few minutes, an EMS-only approach might show better performance increments if post additions are concentrated on large call hotspots. To test this, the city of Assen was considered.

The illustration below shows the estimated driving ranges for the city of Assen. Although almost all of Assen is covered for 8 minutes, only a small section has 4 minute coverage.

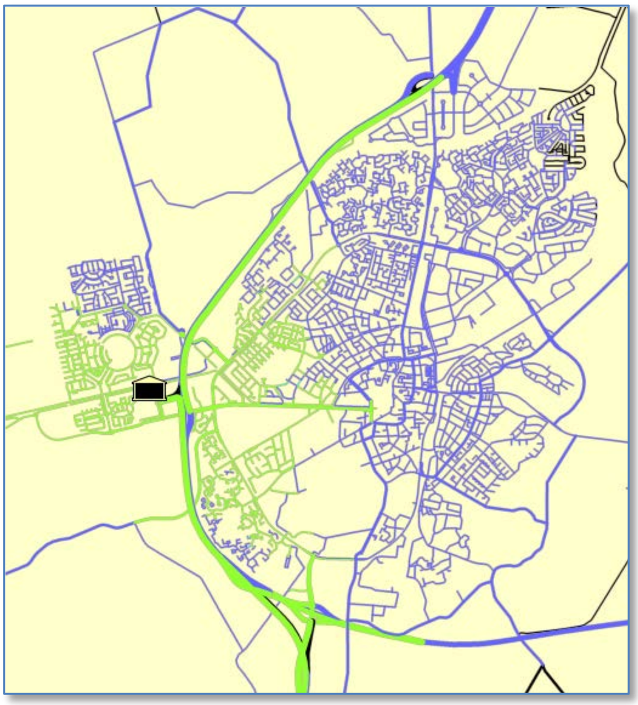

Figure 50: coverage of Assen by 1 post. Green = 4 min, blue = 8 min.

Two variations to the baseline scenario are tested for the city of Assen. In the first one, an additional post is added in the north, providing additional area coverage. In the second one, an additional post is added in the center, to be as close as possible to as much as possible calls. An illustration and the results are shown below.

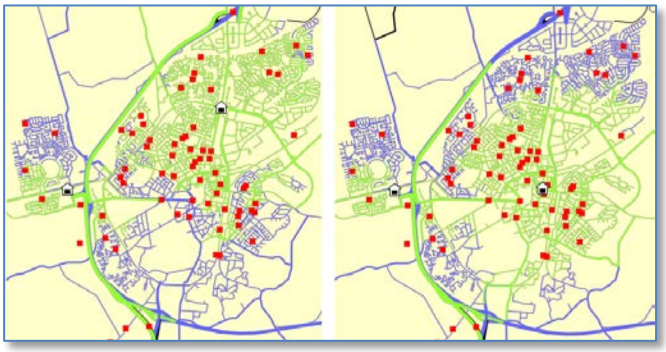

Figure 51: two scenarios with an additional post in Assen. Left: Assen North. Right: Assen Centre.

	4 min	8 min	12 min	survival
40a. Baseline	7%	51%	86%	11.5%
50b. + Assen North	10%	54%	86%	12.6%
50c. + Assen Center	11%	53%	86%	12.9%

Table 14: results for the Assen scenarios.

These results may seem counterintuitive at first: adding one post in Assen contributes more to estimated survival rates in an ambulance-only system than adding three posts throughout the entire region. However, it is a fact that the most survival gain can be achieved in the first few minutes after a victim collapses. Since the urban area of Assen is a call hotspot, the many calls with a minor increase in the first few minutes contribute more to the expected survival rate than a few calls in rural areas.

7.6 Hybrid systems

7.6.1 Full scale hybrid systems

The performance gain may increase further higher when multiple networks are used. The following configurations have been tested region-wide:

- EMS network + firefighters
- EMS network + police
- EMS network + firefighters + police

The baseline settings for each of the individual networks have been used. Review the previous sections for those settings. The results of the hybrid systems are shown below. Figures that illustrate the hybrid systems are also shown below.

	4 min	8 min	12 min	survival
40a. Baseline	7%	51%	86%	11.5%
60a. + F baseline	17%	74%	97%	17.6%
60b. + P baseline	10%	56%	86%	12.7%
60c. + F base. + P base.	19%	78%	98%	18.6%

Figure 52: results for hybrid networks simulations.

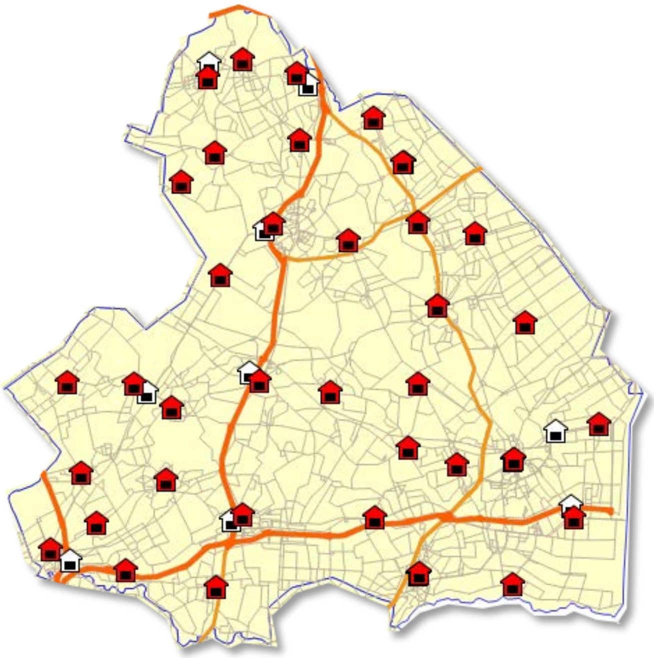

Figure 53: hybrid firefighters network and EMS network.

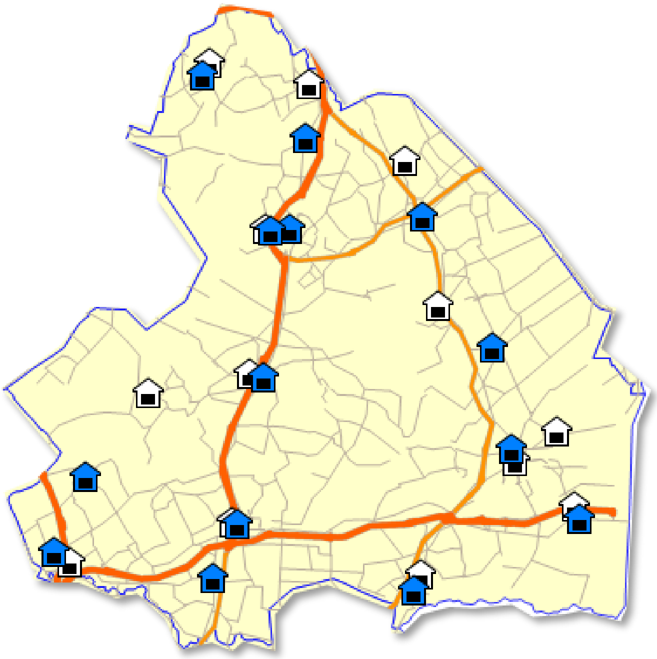

Figure 54: hybrid police and EMS network.

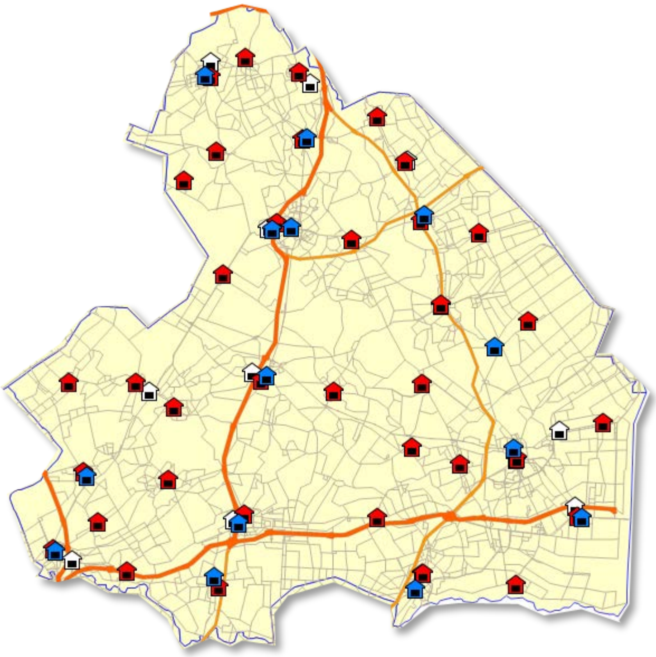

Figure 55: hybrid police, fire services and EMS network.

As expected, the results are the best when all three networks are used. The survival rates depicted here assume that no CPR is given specifically by volunteers. It should be noted that incorporating the police network has only minimal impact. This was already expected due to earlier standalone network simulations of the police network (section [**7.4.4**]). As noted before in section [**7.3.1**], full scale simulation for the volunteer and AED networks was infeasible due to calculation performance issues. Hence, some small scale simulations are tested to adjust the estimated survival rates and responsiveness.

7.6.2 Adjust survival rates for given CPR

The survival rates of the hybrid systems in section [**7.6.1**] can be further improved is CPR is given by volunteers. As noted earlier, the volunteer network is the only network that seems to be able to arrive very quickly at the scene. The response time distribution of volunteers for the city of Assen is the following:

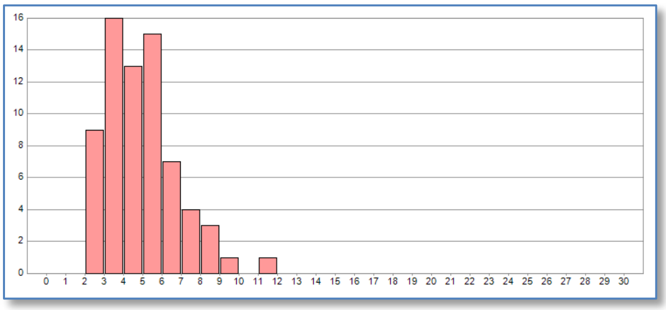

Figure 56: response time distribution for volunteers in the baseline scenario in Assen (scenario 01a).

Using this distribution, the beneficial impact of CPR can be put into the survival function, which can be used to adjust the estimated survival rates of the hybrid systems in the previous section. However, the volunteer distribution of Assen is unique and cannot just be applied to the region wide. However, urban areas have very similar volunteer densities (see section [**6.7.3**]) and the urbanization of Drenthe is 50%. Hence, it is assumed that 50% of all calls can benefit of this particular volunteer response time distribution.

The results are shown below. They should be interpreted with care: for example, these scenarios do not include AED usage by volunteers. Also, it neglects the fact that non-registered volunteers may have given CPR to a victim.

	Baseline volunteer response time	50% volunteer density	25% volunteer density	No CPR
40a variations EMS	14.5%	13.8%	13.3%	11.5%
60a variations EMS + firef.	21.2%	20.4%	19.7%	17.6%
60b variations EMS + police	15.7%	15.1%	14.5%	12.7%
60c variations EMS + F + P	22.2%	21.3%	20.7%	18.6%

Table 15: region-wide hybrid systems with CPR.

An estimate of the interactions between the AED network and the volunteer network can also be made. Unfortunately, combining volunteer arrival data and AED arrival data accurately showed to be impossible using the given tools. Hence, it was chosen to go calculate the survival rates by assuming that any AED arrival had at least t minutes of CPR before that. The results for 1, 2 and 3 minutes CPR before AED defibrillation are shown below.

Reference baseline	Baseline survival	1 min CPR	2 min CPR	3 min CPR
10a variations AED baseline	7.0%	8.0%	9.1%	10.3%
13a variations Double density	11.9%	13.5%	15.3%	17.1%
14b variations d200%, x2, t_{mob}=2	18.9%	21.1%	23.4%	25.8%

Table 16: AED network performance with CPR given up front.

The most significant increase can be found in adjusted versions of scenario 14b, which represents a double AED density and travel speeds. It reconfirms the strong relation between a dense volunteer network with supporting AED network.

For an overview of all the scenario results in this chapter, see Appendix [**G**].

7.7 Final redesign proposal

The following redesign of the system is proposed, based on all the previous findings.

7.7.1 Primary network remains unchanged

The primary network, the EMS network, remains unchanged. The current post locations are based on a call hotspot strategy, which is the best strategy for OHCA calls. Moving posts or adding posts has only minimal impact. The addition of three new posts in Drenthe is estimated to only increase the survival rate with 1.0% (from 11.5% to 12.5%). Operating three additional post fully costs 2.1 million euros, making the annual cost 2.1 million euros per percent of survival rate increase. This is considered to be infeasible.

7.7.2 Include the firefighters and police network

On a region-wide level, use a hybrid EMS, firefighters and police system to deliver defibrillation. There are 36 firefighting posts and 14 police posts, which create a much denser network than the EMS network. If 3 vehicles per post were equipped with an AED, the investment would be (36+14) x 3 x 1500 = 225.000 euros. Training costs for AED usage are low, since training will take only one day. For a yearly check-up, and one training day each year, the operational additional costs would be 30000 euros annually, based 150 persons that receive a 200 euro single-day training. Maintenance costs are also only a few thousand euros annually, as a technical maintenance check-up every few years is the only requirement. The estimated increase in survival rates for this addition is 7.1% (from 11.5% to 18.6%). Hence, the investment cost per percent of survival rate increase is 31500 euros; the annual costs are several thousands of euros per percent of survival increase. These are considered to be very cost-effective measures.

7.7.3 Equalize volunteer response probability

Always alert volunteers, because they are the only ones that are effectively able to arrive within 4 minutes and initiate CPR. Volunteer behavior data should be collected to support future policy and decision making. The EMS providers should actively collaborate with volunteer management to equalize the estimated volunteer response probabilities. As this is a function of the number of volunteers per square kilometer, these should be equalized throughout the province as much as possible too. Currently, there are too many rural areas that have only 1 or 2 volunteers per square kilometer. Urban areas are often much better covered, with some specific neighborhoods having densities above 10 volunteers per square kilometer. Assuming that most volunteers will respond to an alert, and will travel between walking and cycling speeds after at least one minute of mobilization, a minimum of 5 volunteers per square kilometer is advised.

7.7.4 Increase the amount of public AEDs

The number of AEDs that are registered is too low to effectively contribute to survival rates. Currently, AEDs in urban areas such as Assen can only yield survival rates of 4.8% - 7.0% if used stand-alone. This is based on the assumptions that the AEDs are quickly found, collected by foot and without intervention of an EMS provider. As AEDs have more time to arrive at a scene (up to 8 minutes if CPR is provided), the general public should be informed that it may be worthwhile to use faster transportation, because the initial mobilization times of bicycles or cars will diminish quickly after a few minutes of travel time.

An AED density increase of 100% translates to 230 new AEDs in Drenthe. By merging the call data from UMCG Ambulancezorg, the volunteer alert data from the MKNN control center and the current AED location data from HartslagNu, tactical AED locations can easily be determined. This investment is relatively low-cost (230 x 1500 = 345.000 euros). Given the expected gains in survival rates of 4.9% (from 7.0% to 11.9%), this is still only 70.400 euros per percent of survival rate increase.

The combination of double AED density and a volunteer that is enabled to travel with biking speeds gives very good results. Even if this would imply a longer mobilization time (2 minutes instead of 1), the estimated survival rate would increase to 18.9% in a system in which only volunteers would do the defibrillation without provided CPR up front.

7.7.5 Approach OHCA treatment as a chain of care providers and share data

OHCA treatment cannot be done by EMS providers alone. Investing in an EMS-only solution is cost-ineffective. Hence, the networks of the volunteers, AEDs, firefighters, police and EMS need to work as a chain. After an alert, the control center immediately alerts all networks. Volunteers provide CPR within 4 minutes as a first step. They can also immediately defibrillate in the more populated areas. Firefighters, police and EMS are the second link, and can defibrillate within 8 minutes in those places where volunteers are lacking. Finally, the EMS provider arrives no more than 12 minutes after collapse to stabilize the patient and provide transport to the hospital for post-resuscitation care.

Such a chain of care providers can only actively cooperate and operate responsibly if they share information. In order to do this, they need to collect data about their operations first. For Drenthe, the EMS provider and the MKNN control center currently already collect data in a standardized manner. However, the data collection practices for OHCAs need to be improved, since the data contains a considerable amount of noise. The firefighters, police and volunteer managers should collect more data about their operations.

7.7.6 Total redesign performance

This redesign should lead to a survival rate of at least 18.6% region-wide, when not any volunteer or AED interactions are considered. However, the results suggest that urban areas that are operating without EMS, firefighters or police, should be able to achieve a survival rate up to 25.8%, only using the volunteer and AED networks. Both these numbers will increase further if all networks would operate together in a dynamic setting, both in urban and rural settings. This was not tested in this thesis, so estimations for this are not available and subject to further research.

For the response time performances, region-wide suggested standards (especially based on scenario 01, 02, 40a, and 60c) that seem achievable are:

- 30% receives CPR within 4 minutes
- 80% receives defibrillation within 8 minutes
- 90% receives advanced care within 12 minutes

Urban areas can rather easily perform better and should use these suggested standards:

- 50% receives CPR within 4 minutes
- 90% receives defibrillation within 8 minutes
- 98% receives advanced care within 12 minutes

The investment cost for the proposed redesign is fully attributable to the investment of AEDs. The proposal is place 230 AEDs, which costs 345.000 euros. It costs about 225.000 euros to equip the 150 proposed vehicles of firefighters and police costs. Annual training costs will be around 30.000 euros. Annual maintenance costs are negligible.

8. Conclusions

An out-of-hospital cardiac arrest (OHCA) is cessation of cardiac mechanical activity that is confirmed by the absence of signs of circulation and occurs outside a hospital setting. The problem owner of this thesis, UMCG Ambulancezorg, is the Emergency Medical Services (EMS) provider of Drenthe and wants to know what they can do to increase the survival rates of the hundreds of yearly OHCA victims. The general framework for effective OHCA treatment is the Chain of Survival:

1. timely recognition
2. timely cardiopulmonary resuscitation (CPR)
3. timely defibrillation
4. timely advanced life support (ALS)

A more timely response to any of these steps will increase the survival rates. The limits to execute these four consecutive steps should be 4, 4, 8 and 12 minutes, respectively. Hence, the goal is to provide suggestions for an EMS network redesign under justifiable costs that increases responsiveness and meets these limits. The methods and tools that have been used are data analysis in spreadsheet software, crude simulation models in Plant Simulation and more detailed geographical information systems (GIS) modeling in Optima Predict. Quantitative input data was EMS call data, volunteer alert data, average ambulance speed data for the roads and location data of registered volunteers and AEDs. Qualitative data was extracted through interviews with many people of the MKNN, UMCG Ambulancezorg and Hartslag voor Nederland.

The results show that it is impossible for UMCG Ambulancezorg to provide all the steps of the Chain of Survival in an adequate manner without astronomical costs. The skills and procedures within UMCG Ambulancezorg are sufficient for adequate care upon arrival. Unfortunately, timely arrival is in most cases impossible, especially in rural areas. Even the addition of three new fully manned posts, which would cost about 2 million euros annually, would increase the survival rates with only 1 percent, making it a very cost-ineffective solution. Maybe surprisingly, adding just 1 post near a call-hotspot has a larger impact on the full-system survival rates, because this leads to a larger share of calls that are served timely enough to make a difference. A significant increase in network speeds through dedicated infrastructure or using a rapid-responder-only system for OHCAs also increases the survival rate only marginally and presents other difficulties, such as quality and work safety issues.

The only way to cost-effectively attain good responsiveness is by relying on supplementary networks. Four other possible networks have been considered: those of the firefighters, police, registered volunteers, and registered AEDs.

The responsiveness region-wide can be increased significantly by making use of the firefighters network and police network. These extend the 13 posts of UMCG Ambulancezorg with an additional 36 and 14 posts, respectively. Especially the dispersed post locations of the firefighters offer great advantages. When the service cars of volunteers in the firefighters network and police network would be equipped with an AED, the survival rates show a potentially large increase. This does require active dispatching for OHCA calls and comparable mobilization times as the EMS network currently has. In such a case, the baseline estimated survival rate increases from 11.5% to 18.6%. The investment costs of this policy are only 225.000 euros, which is considerably cheaper than adding three fully operating EMS posts (2 million euro). The major share of annual costs is training, which will cost about 30.000 euros.

The survival rates can be increased further by actively incorporating a volunteer network. Volunteer management should be more data-driven in the future; a first step is to collect output-data of volunteer alerts. Also, volunteer densities should be at least several volunteers per square km and be evenly distributed, and the number of publicly registered AEDs should at least be doubled. In a simulated urban volunteer-only network with AEDs this resulted in survival rates of 17.1% - 25.8%, assuming that an advanced care provider arrives immediately after a volunteer has done the defibrillation. A full-scale simulation of all five networks together - EMS, volunteer, AED, firefighters and police - was not possible, but the survival rates will rise even further. However, rural areas remain a challenge, as neither of all five networks is dominantly present there.

The costs for establishing a functional volunteer network are low, as the alerting infrastructure has already been implemented and is operational. The main focus should therefore be in expanding the volunteer base and response probability. This research did not quantify the costs of this and is subject to further research. A doubling of AEDs translates to 230 new AEDs. Placement needs to be done through an OHCA call-hotspot approach. The addition of these 230 AEDs throughout the province will cost an additional 345.000 euros. Hence, the total investment costs for the full redesign is about half a million euros and primarily attributable to newly installed AEDs; the total variable costs are much less and will cost a few tens of thousands of euros annually.

9. Further research

The redesign in chapter [**7**] and the subsequent suggestions in chapter [**8**] have been limited to a socio-technical redesign. Hence, further research could extend the presented redesign to other disciplines, to refine the implementation process. For example, the most (cost-) effective strategy for expanding the volunteer base is a possible topic for further research. Another possible area is to explore the behavioral differences between the organizations that are active within the firefighters, police and EMS network. This should lead to a better synthesis in daily operations when responding to OHCA calls.

Further research within the research discipline of this thesis could focus on the simulation of multiple networks simultaneously. Unfortunately, this was only partially possible with the tools used in this thesis, or it involved workarounds; it even seems that there is not yet a powerful enough GIS-oriented simulation package available on the market. Hence, development of such a tool may be worth research in itself.

The supplementary networks under consideration in this research were those of the firefighters, police, volunteers and AED. There may be interesting other (existing) networks that could provide promising results. One network that specifically comes to mind is the network of general practitioners.

Other further research could focus on how to deliver better quality data for the networks that have been considered in this thesis. There was hardly any performance data available for the supplementary networks, and neither was it possible to collect reliable data without a considerable time span. Especially measuring the performance of a volunteer network is interesting research; for the Netherlands the results from such a research is expected to be presented in short notice for the area of Limburg. This research could be repeated for other regions, or the data from that research could be used to improve the current simulation models.

Another suggestion is research into effective data-sharing platforms. Although especially UMCG Ambulancezorg and the MKNN started collecting data, hardly any data is shared or received from other potential relevant parties, such as Hartslag voor Nederland, that has knowledge about volunteer networks.

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10. Appendices

A. Motivation for limitations and focus

Originally, the problem owner wanted to gain more knowledge about large system disruptions. Hence, one of the tasks was to explore calls that require multiple EMS vehicles. Hence, a classification of Single Emergency Response Incidents (**SERI**) versus other types was quickly made. One of these types is an OHCA. These usually require two vehicles due to high labor demands. Also, very high levels of expertise are required very timely at the incident scene. Two other distinctive types of incidents are Multi Casualty Traffic Indicents (**MCTI**), of which there are several dozens each year, and disasters, which occur less than once per year.

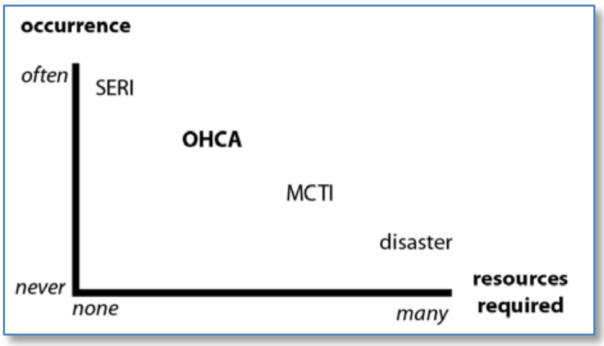

Figure 57: OHCAs positioned within other classes of incidents.

OHCAs are particularly interesting, because of its relatively high occurrence and because of the high link between timely response and favorable survival outcome.

Alternatively, the other types may be excluded for the following reasons. First, SERIs are excluded because the topic of *overall* response time performance improvement has already recently been covered by another graduate (van Werven, 2012). Second, MCTIs are exluded because its impact was considered to be too low, given that they only occur several dozen times per year. Historical data (2011) confirms the maximum amount of vehicles sent was only six (The Optima Corporation, 2013). Also, improving response times or survival for MCTIs is especially possible in vast, rural areas, which is not applicable to this region (Gonzalez, Cummings, Phelan, Mulekar, & Rodning, 2009), (Sánchez-Mangas, García-Ferrrer, de Juan, & Arroyo, 2010). Third, disasters are excluded because they are too rare to be worth optimizing for: they occur less than once per year (Nationaal Brandweer Documentatie Centrum, 2012). Also, the margin for improvement is limited since the goal of an EMS provider automatically changes from achieving adequate response times to just trying to meet transport demand in those cases (Tierney, 1985).

B. Location and relocation models

Classical models (before 2000)

The older models (before 1980) generally use FIFO call queuing, assign the closest ambulance, and have no add-on mutations. Examples of such location models are the following:

- **LSCP** *[Location Set Covering Problem]* (Toregas, Swain, ReVelle, & Bergman, 1971). This model minimizes the number of vehicles to attain certain coverage.
- **MCLP** *[Maximal Covering Location Problem]* (Church & Revelle, 1974). This model maximizes coverage, given an amount of vehicles.
- **TEAM** *[Tandem Equipment Allocation Model]* (Schilling, Elzinga, Cohon, Church, & ReVelle, 1979). This model is the first one that includes priority-based dispatch.

The next generation of models (1980-2000) is still static, i.e. these models use no relocations, but start to experiment with alternate call queuing and probabilistic elements. Examples include the following:

- **MEXCLP** *[Maximum Expected Covering Location Problem]* (Daskin, 1983) gives all ambulances in the system a uniform probability of being busy.
- **AMEXCLP** *[Adjusted Maximum Expected Covering Location Problem]* (Batta, Dolan, & Krishnamurthy, 1989) multiplies the objective function by a correction factor that accounts for the fact that ambulances do not operate independently. Hence, this model incorporates multi-server queuing effects.
- **QPLSCP** *[Queuing Probabilistic Location Set Covering Problem]* (Marianov & ReVelle, 1994) gives all ambulances *unique* busy probabilities. These can be estimated using analytical tools such as the hypercube model (Larson, 1974), iterative algorithms like the CZSR heuristic (Fitzsimmons & Srikar, 1982), or through simulation.

Modern static models

- **DDSM^t** *[Dynamic Double Standard Model at time t]* (Gendreau, Laporte, & Semet, 2001) is the dynamic version of their earlier static location model, the Double Standard Model.
- A **MCM** *[Markov Chain Model]* approach (Alanis et al., 2013) can be used to generate compliance tables.
- **DACL** *[Dynamically Available Coverage Location]* (Rajagopalan et al., 2008) **ADP** *[Approximate Dynamic Programming]* (M. S. Maxwell, Restrepo, Henderson, & Topaloglu, 2009). These models are tailored towards day-to-day operations: they relocate ambulances to obtain general maximal coverage.

Modern dynamic models

- Markov Decision Process approaches (Mclay, Mayorga, & Bandara, 2012) and (McLay & Mayorga, 2013). For example, they may combine call prioritization with local call volumes to incidentally send non-closest vehicles to incidents. Both models show that they outperform a closest-dispatch policy.
- Simulation approaches with an area districting heuristic (Mayorga et al., 2013). This model tries to send ambulances according to an intra-district policy. However, if all ambulances in a district are occupied, an inter-district policy is activated.
- **DYNAROC** (Andersson & Värbrand, 2007) uses a preparedness function to dispatch ambulances. This function includes the number of available ambulances, their travel times to a zone of interest and the number of recent local calls. The preparedness function may be extended with average income and income inequality (Lee, 2010).

C. Post location strategy matches

Call hotspot match

City	Has post?
Assen	Yes
Beilen	Yes
Coevorden	Yes
Eelde-Paterswolde	Yes
Emmen	Yes
Hoogeveen	Yes
Klazienaveen	Yes
Meppel	Yes
Roden	Yes
Zuidlaren	**No**

Figure 58: overview of the 10 largest cities in Drenthe and whether there is a post in it.

Main infrastructure match

Post identifier	Highway within 200 m?	Major roads within 1 km
Annen	No	Spijkerboorsweg
Assen	Yes	A28
Beilen	No	A28
Borger	Yes	N34
Coevorden	Yes	N382 N34
Dieverbrug	No	N371
Emmen	No	Ermerweg
Emmen Noord	No	N391
Hoogeveen	No	A28
Klazienaveen	Yes	A37
Meppel	Yes	A32
Roden	No	N373 N372
Tynaarlo	No	A28

Table 17: an overview of fast infrastructure near posts.

D. Data sets

This thesis uses both qualitative and quantitative data. The qualitative data comes from both formal and informal interviews, conversations and observations from various employees within UMCG Ambulancezorg, the control center and foundation HartslagNu. In both cases, both management and lower level employees have been interviewed. The quantitative information also comes from various sources and there are several distinguishable data sets: historical ambulance call data, volunteer alert data, volunteer distribution data, AED distribution data, and population data. Below is an elaboration about these data.

Historical ambulance call data

The historical ambulance call data originates from multiple sources. In the control center, call data is put into the ‘Geïntegreerd Meldkamer Systeem’ (**GMS**). This is transferred to the ‘Landelijke Server Voertuigen’ (**LSV**) and then to the server of the ‘Electronisch Dossier Ambulancezorg’ (**EDAZ**). This flow is visualized through steps 1a - 1d in the diagram further below. Staff on the ambulances receives this info and completes the call data with information about the ride and the patient (step 2). The data then travels back through the LSV server to the GMS server and is completed with time data (steps 3a, 3b, 4). Finally, it is pushed to the OpenCare Server.

Some other EDAZ data goes directly to the OpenCare server (step 5) and is merged afterwards with the data in step 4. When both GMS and EDAZ try to push data to the same field in the OpenCare server, there is a logic that determines which source is leading (figure 58). The ambulances also send their GPS coordinates separately to CityGIS (www.citygis.nl), a company specialized in providing graphical information solutions for control centers. UMCG Ambulancezorg asked The Optima Corporation ([www.theoptimacorporation .com](www.theoptimacorporation.com)) to link their call data with these GPS data from CityGIS.

This results in the following possible datasets:

- GMS dataset: raw call data
- EDAZ dataset: raw patient and ride data
- OpenCare dataset: merged MGS and EDAZ data.
- Optima dataset: manually merged data from OpenCare and GMS, enriched with GPS.

In theory, this makes the Optima dataset the most favored one, as it contains the most information. Unfortunately, deeper inspection of the data has revealed some issues. There are considerable differences in dataset sizes between OpenCare and GMS (13.6%), missing entries in either databases (1.2% and 8.2%) and false duplicates (5.9% and 0.9%).

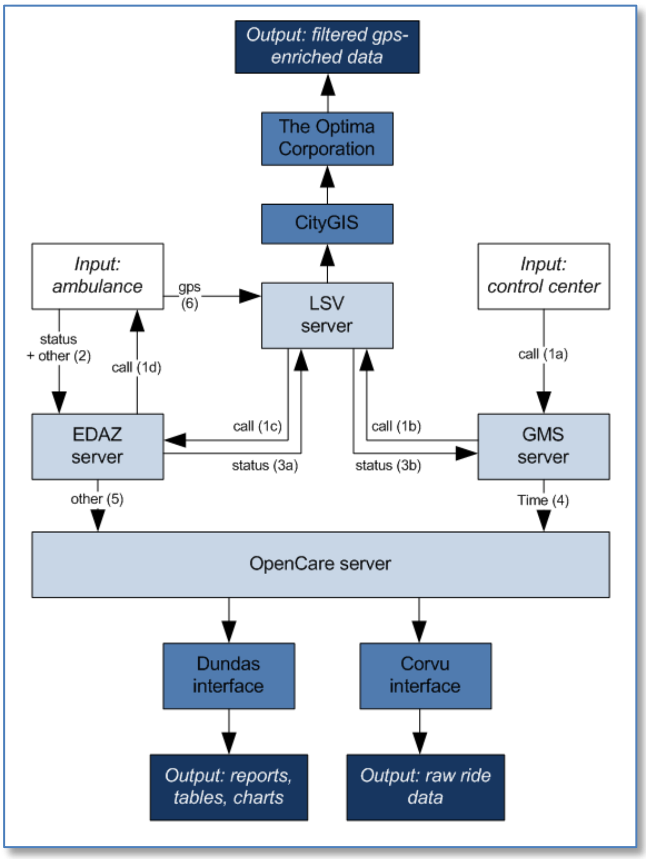

Figure 59: data flow overview.

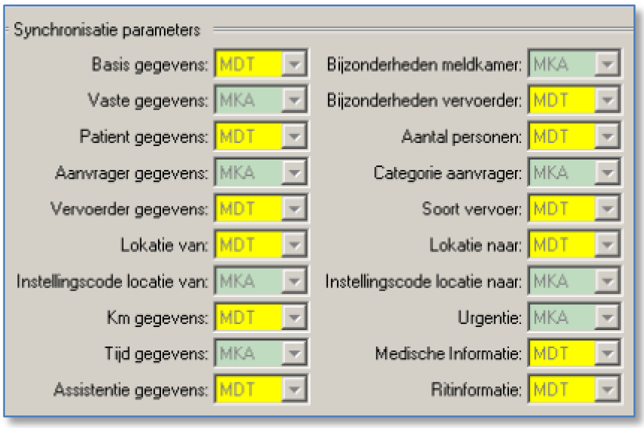
Synchronisatie parameters
Basis gegevens: MDT
Vaste gegevens: MKA
Patient gegevens: MDT
Aanvrager gegevens: MKA
Vervoerder gegevens: MDT
Lokatie van: MDT
Instellingscode locatie van: MKA
Km gegevens: MDT
Tijd gegevens: MKA
Assistentie gegevens: MDT
Bijzonderheden meldkamer: MKA
Bijzonderheden vervoerder: MDT
Aantal personen: MDT
Categorie aanvrager: MKA
Soort vervoer: MDT
Lokatie naar: MDT
Instellingscode locatie naar: MKA
Urgentie: MKA
Medische Informatie: MDT
Ritinformatie: MDT

Figure 60: Data priority per data field if both the GMS (=MKA) and EDAZ (=MDT) push information to the same field in the OpenCare server.

The Optima dataset is still favored as it is the only set with GPS coordinates attached to calls and dispatched vehicles. However, there is another issue: Optima has classified calls as being an OHCA when the ‘hart massage’ field was tagged in the original data. Yet this field is not always tagged, for example, when bystanders already performed the heart massage before arrival, and the vehicle crew only defibrillated. Therefore, the Optima Corporation has only marked 172 and 165 calls for 2011 and 2012 as resuscitation calls, whereas there should be more. Foundation HartslagNu claims that 0.1% of the population is struck with an OHCA each year (HartslagNu, 2013). Other recent Dutch research for the regions Noord-

Holland and Twente reports 0.05% to 0.076% of the population each year (Beesems, Zijlstra, Stieglis, & Koster, 2011). For Drenthe, this corresponds with 250 - 500 OHCAs each year, as the population is roughly 500.000 citizens.

Optima cannot be blamed too much for the low amount of OHCAs in their dataset: the input data also contains a considerable number of flaws. For example, some calls initially marked as 'OHCA' are later stored to 'dead' when resuscitation is not attempted. However, some of these calls would have been successful resuscitations if care would have arrived earlier. The opposite also happens: some calls which start as an 'incapacitation' call change to an OHCA by the time EMS crew arrives. This is also not always logged.

Hence, the dataset of OHCAs (337 total for 2011 and 2012) may contain biases or suffer from other issues with small datasets. Extensive manual data research was done in order to try to correct data or find alternate ways to find useful data, but did not show satisfactory results.

Response time distributions

To reduce the effects of potential bias and a small dataset, some sampled calls were added to the dataset for the simulation purposes. The software used (Optima Predict) allows accurate automatic sampling and filtering of calls. The added calls were randomly sampled A1 calls in the region of Drenthe, under the assumption that these include some of the misdiagnosed calls and that geographical OHCA incidence has a similar spreading as general A1 priority calls. Through this procedure a total of 280 sampled A1 priority calls were added for 2011 and 2012, making the final dataset consist of 617 resuscitation calls over this two-year period.

The response time distributions of the Optima data of 2011 and 2012, and the sampled data are shown below. Note that three outliers (over 30 minutes) have also been removed.

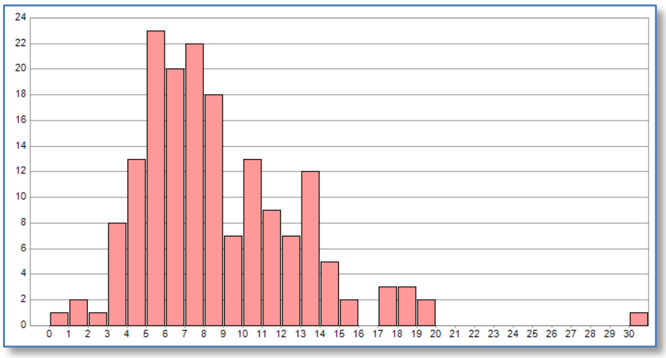

Figure 61: resuscitation calls response time distribution (2011, Optima dataset, 172 calls)

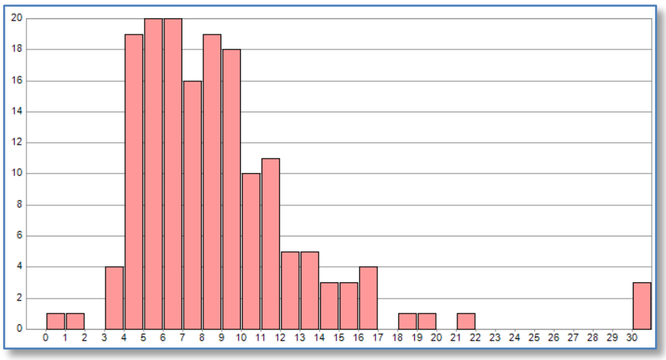

Figure 62: resuscitation calls response time distribution (2012, Optima dataset, 165 calls)

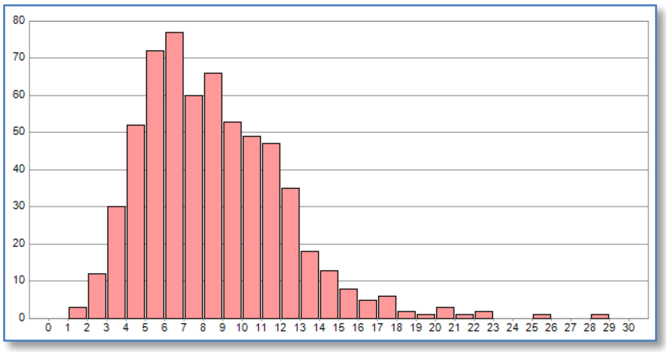

Figure 63: resuscitation calls with sampled data (2011+2012, Optima dataset, 337 A1R calls + 280 sampled A1 calls)

Geographical resuscitation call distribution

The figures below show the geographical distributions of resuscitation calls for 2011, 2012 and the combined set with sampling.

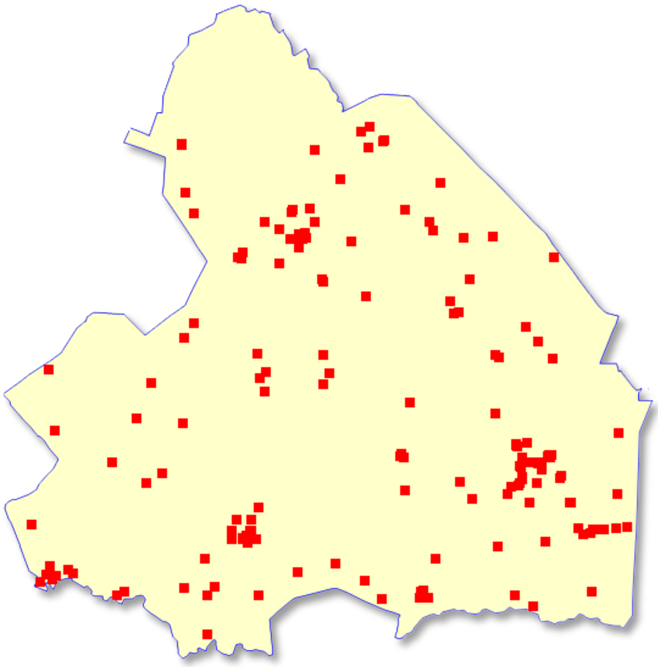

Figure 64: resuscitation calls (2011, Optima dataset, 172 calls)

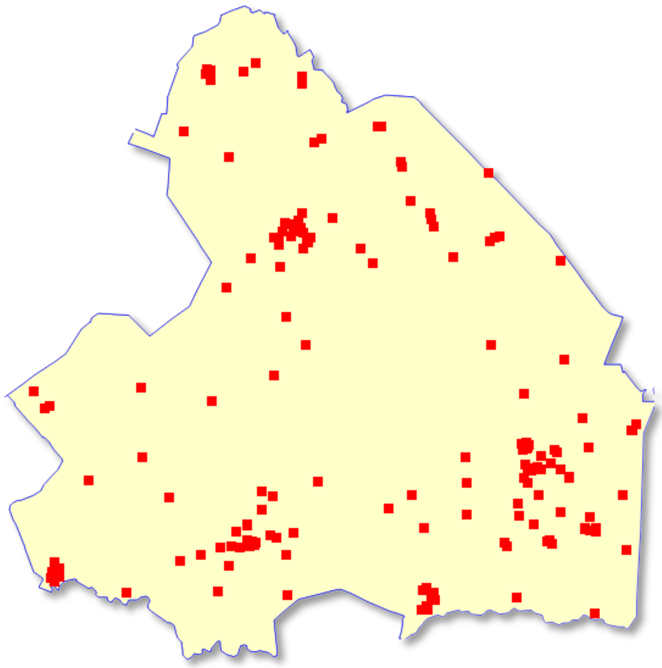

Figure 65: resuscitation calls (2012, Optima dataset, 165 calls)

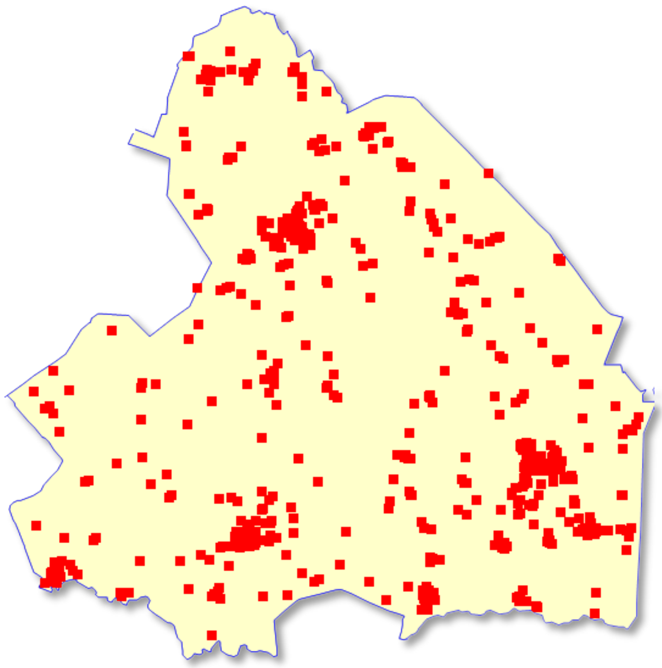

Figure 66: resuscitation calls (2011+2012, Optima dataset, 337 A1R calls + 280 sampled A1 calls)

Call volume per day of the week

One interesting thing in the Optima OHCA data is that especially Mondays there seems to be a higher call volume. This trend is clearly visible for both 2011 and 2012 separately, shown below. There is no explanation for this trend: there may truly be more OHCAs on Mondays, or it may the result of a too small dataset, or there may be a bias in the reporting of OHCAs. This issue definitely deserves further attention in future research.

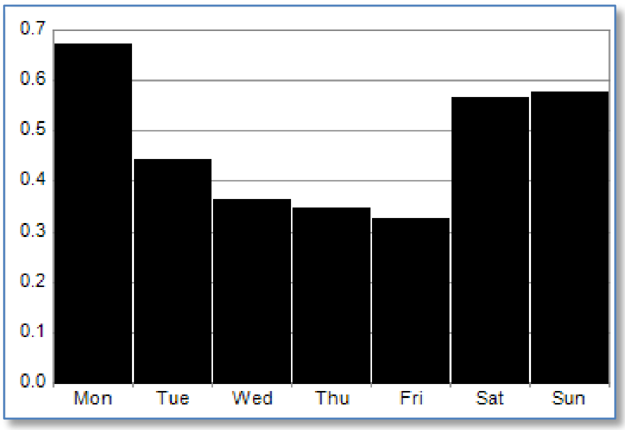

Figure 67: resuscitation call volume, per day of the week (2011, Optima dataset, 172 calls).

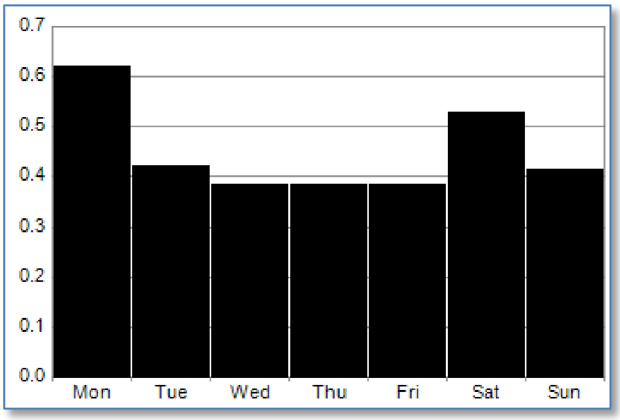

Figure 68: resuscitation call volume per day of the week (2012, Optima dataset, 172 calls).

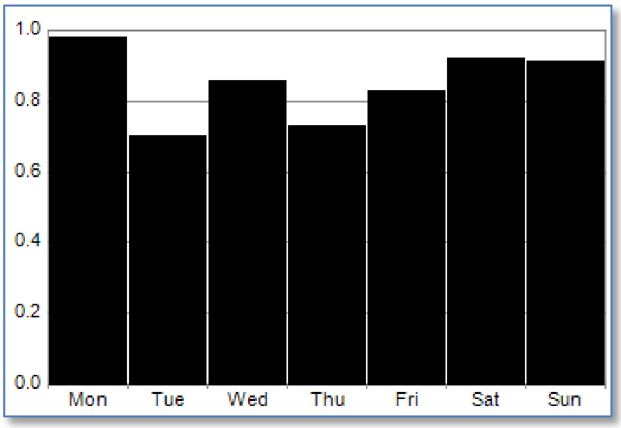

Figure 69: resuscitation call volume, per day of the week (2011+2012, 337 A1R calls + 280 sampled A1 calls)

	2011	2012
Monday	0.67	0.61
Tuesday	0.43	0.41
Wednesday	0.35	0.39
Thursday	0.34	0.39
Friday	0.32	0.39
Saturday	0.56	0.52
Sunday	0.58	0.41
Mean	*0.46*	*0.45*
T-test		***77%***

Table 18: call volume per day and T-test

Although the data between 2011 and 2012 seems rather different, a two sided t-test yields a probability of 77% that the null hypothesis is true. Since this value is larger than 5%, there is no significant difference in the means and the differences are likely due to chance.

Correlation between response time and call volume

There is no decisive correlation between the average call volume per day of the week, and the average response time per day of the week. The correlations are also very small, which makes it rather likely that they are primarily caused by chance.

2011		2012		Both + sampling	
resp time	call vol	resp time	call vol	resp time	call vol
8,6	0,67	9,3	0,61	8,8	0,98
9,0	0,43	8,9	0,41	8,7	0,7
9,3	0,35	9,3	0,39	8,6	0,85
10,1	0,34	9,6	0,39	8,7	0,73
6,5	0,32	8,1	0,39	8,7	0,82
10,0	0,56	8,7	0,52	8,6	0,92
8,2	0,58	8,2	0,41	8,2	0,91
Pearson:	**+0,107**		**+0,199**		**-0,228**

Confidence plots

Below is a plot for the analytical police-model in section [**6.6.3**]. The results in the main text are based on 10.000 replications. The average distance after n replications is plotted below, showing that the reported value after 10.000 replications is not based on an outlier.

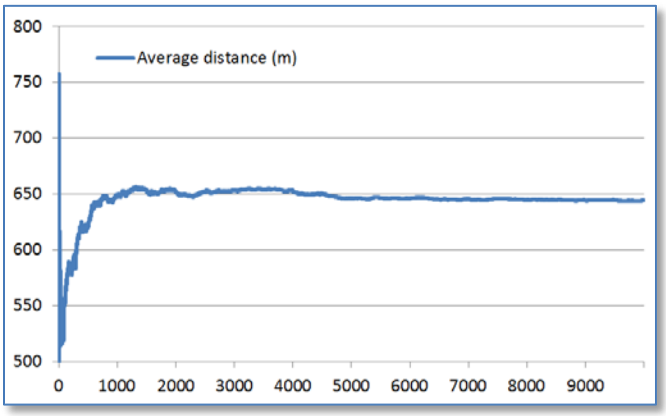

Figure 70: average distance to randomly generated OHCAs. The x-axis shows the number of replications.

Below is a plot for the analytical volunteer-nodes-model, that explores whether the performance on 4, 8, and 12 minutes is dependent on the density of volunteers in some area in section [**6.7.3**]. The results in the main text are based on 1000 replications, when the chart has stabilized.

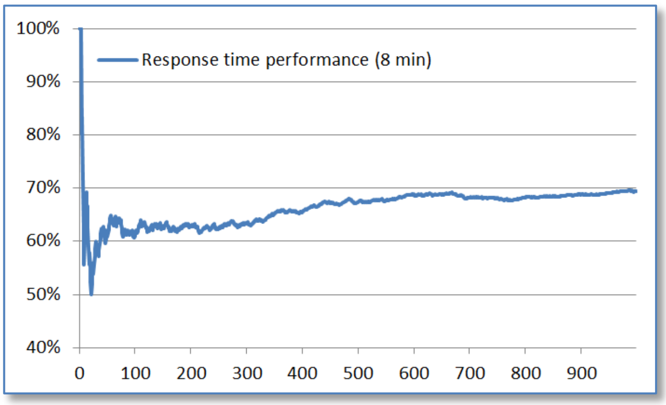

Figure 71: average response time performance for 8 minutes after n replications (x-axis).

Volunteer alert data

The volunteer alert data is stored by foundation Hartslag voor Nederland in a volunteer management platform called HartslagNu (www.hartslagnu.nl), which was initiated by AXIRA (www.axira.nl). AXIRA is a cooperation of multiple EMS providers in the Netherlands.

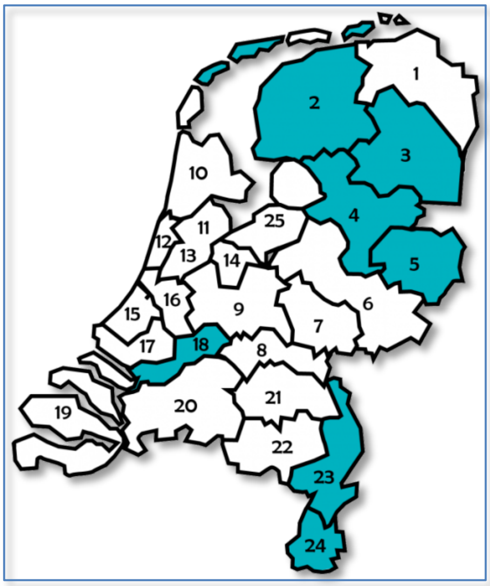

Figure 72: AXIRA is a cooperation of the EMS providers operating in the colored safety regions.

The control centers use the alert system of HartslagNu to alert volunteers and the data from alerts is stored into a database of HartslagNu. This data contains many things, such as: location of the call, all individual alerted volunteers, whether they were ordered to go to an AED, distance to the call.

Volunteer distribution data

People can subscribe to become a volunteer on the website of HartslagNu. This data is stored into a database that is stored by HartslagNu. Some of the data that is stored: address of the volunteer for multiple times if needed, availability, date of last CPR exam, contact data. The control centers use this information to calculate which volunteers need to be alerted.

AED distribution data

Just like volunteers can register themselves on the website of HartslagNu, they can also register AEDs. The data stored is very similar to that about the volunteers themselves: location, availability, last quality check.

Population data

To calculate volunteer and AED densities per region, population data was used. This data originated from the Dutch Central Agency for Statistics (CBS), see www.cbs.nl.

E. Vehicle shifts

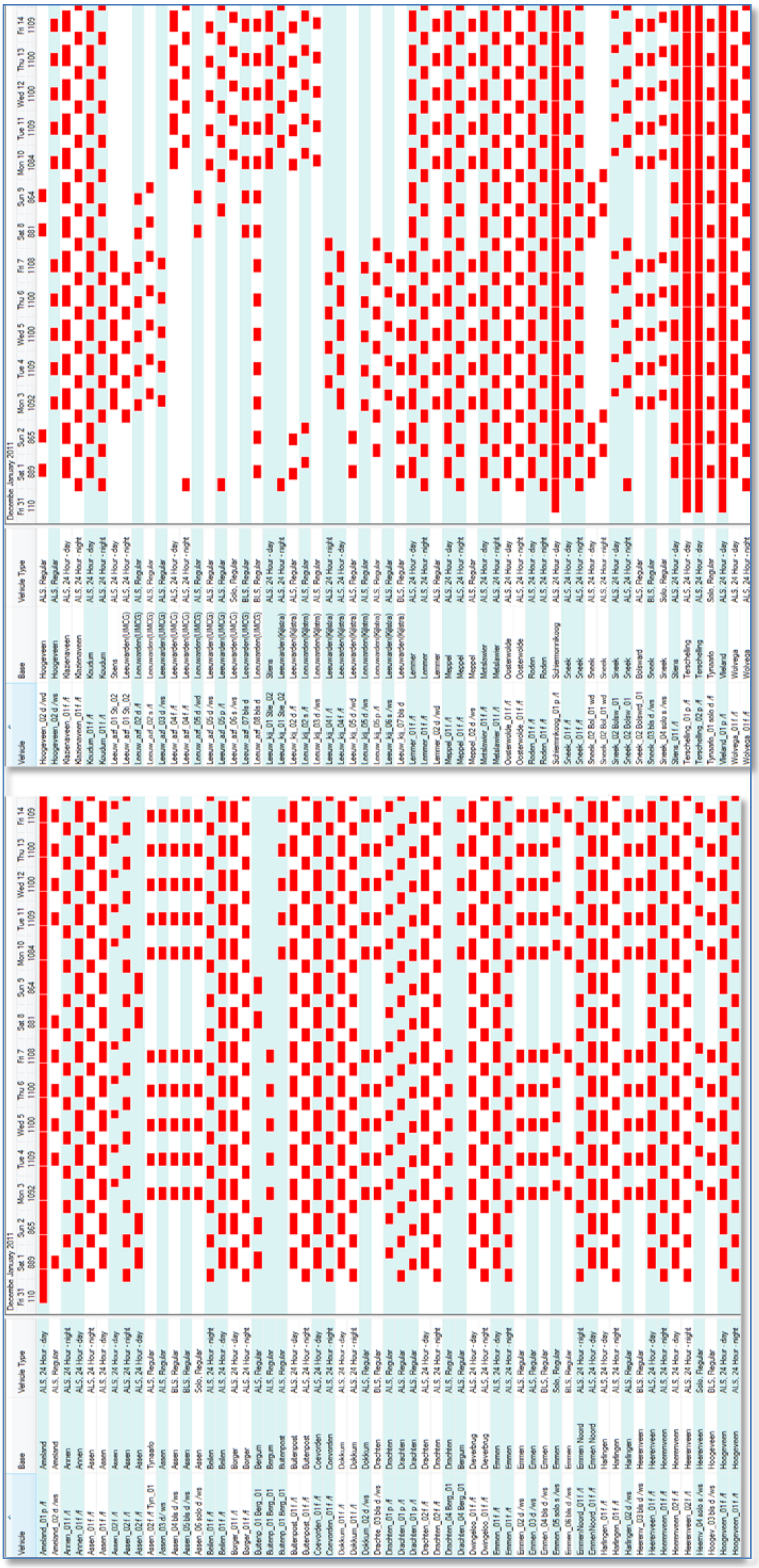

Figure 73: vehicle shift overview. The red areas indicate scheduled working hours.

F. Survival estimation

The performance (the survival rate) is estimated indirectly by using the time until CPR since the collapse, the time until defibrillation since the collapse, and the probability to encounter a shockable rhythm. All other factors are not considered, as there are too many uncertainties in translating this to any meaningful estimate of the survival rate. Literature indicates that the majority of OHCAs begin with VF or another shockable rhythm. This is explained in Chapter 3, and section [**3.7.2**] provides time dependent functions. For simplicity, all shockable rhythms below are referred to as *VF*.

First, the overall survival probability at time t can be decomposed by the individual contributions due to VF and for non-VF rhythms:

$$P_{survival}(t) = P_{survival,VF}(t) \times P_{VF}(t) + P_{survival,nonVF}(t) \times P_{nonVF}(t) \qquad [1]$$

Here, P_{VF} and P_{nonVF} stand for the probability to encounter a VF or nonVF rhythm, respectively. $P_{survival,VF}$ and $P_{survival,nonVF}$ are the corresponding probabilities of survival. Section [**3.7.4**] explained that the survival probability for non-VF rhythms is very small. Some exceptions mention survival rates above five percent, but many hover around a few percent. Hence, expression [1] can be simplified by setting the survival probabilities for non-VF rhythms to zero, which yields:

$$P_{survival}(t) = P_{survival,VF}(t) \times P_{VF}(t) \qquad [2]$$

Survival probabilities for VF rhythms at time t are presented in section [**3.7.1**]. Unfortunately, most of the curves in that section do not differentiate between CPR / no CPR. Two ‘raw’ curves remain: the one from (American Heart Association, 2000) and (Larsen et al., 1993), which are both linear. Hence, the survival probability for VF rhythms can be formulated as a - b*t. However, it needs to be extended to address the benefits of the received CPR since a certain time t_{CPR}. This yields the following expression for the survival probability of VF rhythms:

$$P_{survival,VF}(t) = a - bt_0 + ct_{CPR} \qquad [3]$$

Here, *a* is the initial survival probability, *b* is the survival probability decrease per minute, *c* is the survival probability increase per minute due to CPR, t_0 is the time since the collapse and t_{CPR} is the time since CPR is provided.

The values for a and b can be derived from (American Heart Association, 2000) or (Larsen et al., 1993). The first one, [*100% - 10t]* is too optimistic, the latter one [*67% - 5.5t*] is too pessimistic, because survival rates for VF averaging around 80% right after the collapse have been reported (see section [**3.7.1**]). Hence, these two linear curves are linearly averaged to find more appropriate values for *a* and *b*:

$$\frac{1+0.67}{2} - \left(\frac{0.1+0.055}{2}t_0\right) = 0.835 - 0.0775t_0 \qquad [4]$$

The value of *c* can be found in section [**3.7.2**] (i.e. 5.5% - 3.3% = 2.1%), but since the slope of the curve has been adjusted, this component must be scaled accordingly. Hence, the value of c is:

$$\frac{0.0775}{0.055} \times 0.021 = 0.0289 \qquad [5]$$

Putting [4] and [5] in [3] yields:

$$P_{survival,VF}(t) = 0.835 - 0.0775t_0 + 0.0289t_{CPR} \qquad [6]$$

Expressions for the second component in [2], the probability to find a VF rhythm, can be found in section [**3.7.2**]. The chosen expression here is from (Reinier a Waalewijn et al., 2002), because this is the most recent study and was extracted from Dutch OHCA data, which is therefore expected to be rather similar. The structure of this expression is equal to expression [3]: there is an initial probability to encounter VF, decreases per minute, but may be slowed down with CPR:

$$P_{VF}(t) = a - bt_0 + ct_{CPR}$$

Putting in the parameters from (Reinier a Waalewijn et al., 2002) yields:

$$P_{VF}(t) = 0.75 - 0.03t_0 + 0.0167t_{CPR} \qquad [7]$$

Putting [6] and [7] into [2] yields the following total expression for the overall survival probability at the time of defibrillation t_{def}:

$$P_{survival}(t_{def}) = (0.835 - 0.0775t_0 + 0.0289t_{CPR}) \times (0.75 - 0.03t_0 + 0.0167t_{CPR})$$

$$P_{survival}(t_{def}) < 0 \rightarrow P_{survival} = 0 \qquad [8]$$

To illustrate the behavior of this survival probability function, consider the chart below. The black line shows the survival probability at the moment of defibrillation after t minutes without any CPR. It predicts that there are no more survivors after 10 minutes, if no CPR is provided. The dark grey line represents the case in which CPR is initiated after two minutes. This makes the survival probability decline less rapid. However, after 8 minutes no more CPR is given, which causes the probability to decline faster again. The light grey line represents a case in which CPR is provided after 4 minutes.

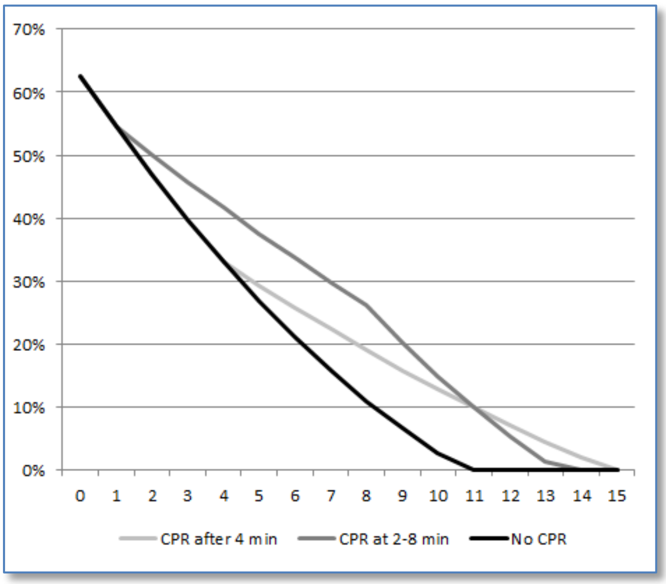

Figure 74: example to illustrate the survival formula behavior.

The non-negativity constraint [8] is added to prevent negative probabilities for large values of t. All other influences on the survival probability after defibrillation are not considered. Hence, the expected amount of survivors from *k* OHCAs can now be calculated by summing all the survival probabilities at the time of defibrillation:

$$E(survivors) = \sum_{1}^{k} P_{survival}\left(t_{def}\right)$$

For clarity, this survival function has the following assumptions:

- the outcome of survival is either success (survivor) or failure (non-survivor).
- the survival probability at any time includes the probability to find a non-shockable rhythm at that time.
- the arrival time of the first shock provider (ambulance or AED) equals the time of defibrillation.
- There is only one defibrillation attempt. The probability of success at that time incorporates any future defibrillations with a possible successful outcome, if the first attempt were to be non-successful.
- at the time of defibrillation it becomes known whether a victim has survived or not.
- the survival probability at the time of defibrillation is fully determined by the probability of finding a shockable rhythm (VF), the time since collapse, and the time since initiation of CPR.
- the probability of finding a shockable rhythm is fully determined by the time since collapse and the time since initiation of CPR.
- hence, the survival probability at the time of defibrillation is fully determined by the time since collapse, and time since initiation of CPR.
- if CPR is initiated, it is continued until the time of defibrillation.

G. Scenarios and performances

All scenario results in Chapter 7 are summarized here for convenience and comparison.

01 - 02: volunteer scenarios in Assen (for timely CPR)				
01a. Baseline (129 volunteers, 8 km/h)	36%	93%	100%	16.4% *
01b. 50% density, 8 km/h	21%	86%	99%	14.0% *
01c. 25% density, 8 km/h	11%	68%	95%	11.1% *
02a.100% density, 16 km/h	70%	100%	100%	20.2% *
02b. 50% density, 16 km/h	49%	99%	100%	18.9% *
02c. 25% density, 16 km/h	34%	97%	100%	17.1% *
10 - 14: AED scenarios in Assen (for timely defibrillation)				
10a. Baseline (10 AEDs, 8 km/h)	6%	28%	68%	7.0%
with 1 minute of CPR before AED arrival				8.0%
with 2 minutes of CPR before AED arrival				9.1%
with 3 minutes of CPR before AED arrival				10.3%
10b. 100% density, mobilization time = 2	1%	22%	57%	4.9%
11a. 100% density, 16 km/h	17%	81%	94%	18.2%
11b. 100% density, 16 km/h, mobilization time = 2	6%	67%	94%	13.6%
12a. 150% density	9%	45%	94%	10.3%
12b. 150% density, mobilization time = 2	3%	30%	84%	7.2%
13a. 200% density	10%	54%	96%	11.9%
with 1 minute of CPR before AED arrival				13.5%
with 2 minutes of CPR before AED arrival				15.3%
with 3 minutes of CPR before AED arrival				17.1%
13b. 200% density, mobilization time = 2	3%	36%	87%	8.3%
14a. 200% density, 16 km/h	29%	97%	100%	24.4%
14b. 200% density, 16 km/h, mobilization time = 2	10%	94%	100%	18.9%
with 1 minute of CPR before AED arrival				21.1%
with 2 minutes of CPR before AED arrival				23.4%
with 3 minutes of CPR before AED arrival				25.8%
20: Firefighter scenarios region-wide (for timely defibrillation)				
20a. Baseline (36 posts, A2 EMS speeds, night EMS mobilization time)	13%	67%	94%	10.7%
20b. 4-6 minutes uniform mobilization time	0%	7%	50%	1.7%
20c. 2-4 minutes uniform mobilization time	0%	26%	70%	5.2%
20d. Travel speeds according to A1 priority calls on EMS network	13%	66%	94%	15.2%
30: Police scenarios region-wide (for timely defibrillation)				
30a. Baseline (14+14 posts+ghost, A1 EMS speeds, 0-8 min mob-t)	4%	34%	77%	7.9%
30b. 0-6 minutes mobilization time	6%	45%	83%	9.9%
30c. 0-4 minutes mobilization time	10%	55%	88%	12.8%
30d. No ghost posts (only the 14 regular posts)	4%	55%	88%	6.6%
40 - 50: EMS scenarios region-wide (for timely advanced care)				
40a. Baseline (13 posts)	7%	51%	86%	11.5%
40b. Extra post in Havelte	7%	51%	86%	11.6%
40c. Extra post in Westerbork	7%	53%	86%	11.8%
40d. Extra post in Schoonebeek	8%	53%	87%	11.9%
40e. Extra post in Havelte, Westerbork and Schoonebeek	9%	55%	89%	12.5%
40f. Speeds are 120% for all roads	11%	61%	93%	14.0%
40g. Speeds are 200% for selected major roads	8%	55%	88%	12.4%
40h. Only three aircrafts in Assen, Hoogeveen and Emmen	0%	31%	72%	5.3%
50b. Extra post in Assen North	10%	54%	86%	12.6%
50c. Extra post in Assen Center	11%	53%	86%	12.9%
60: Hybrid systems region-wide (+ variations)				
60a. EMS baseline + Firefighters baseline	17%	74%	97%	17.6%
+ 01a. with baseline volunteers in urban areas				21.2%**
+ 01b. with 50% volunteers in urban areas				20.4%**
+ 01c. with 25% volunteers in urban areas				19.7%**
60b. EMS baseline + Police baseline	10%	56%	86%	12.7%
+ 01a. with baseline volunteers in urban areas				15.7%**
+ 01b. with 50% volunteers in urban areas				15.1%**
+ 01c. with 25% volunteers in urban areas				14.5%**
60c. EMS baseline + Firefighters baseline + Police baseline	19%	78%	98%	18.6%
+ 01a. with baseline volunteers in urban areas				22.2%**
+ 01b. with 50% volunteers in urban areas				21.3%**
+ 01c. with 25% volunteers in urban areas				20.7%**

* = the time of defibrillation was set to 12 minutes in these scenarios to illustrate the effects of CPR.

*/** = these have not been simulated stand-alone, but calculated after simulating its reference scenario.