Improving the response time performance of A1-priority calls for UMCG ambulancezorg

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IMPROVING THE RESPONSE TIME PERFORMANCE OF A1-PRIORITY CALLS FOR UMCG AMBULANCEZORG

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MANAGEMENT SUMMARY

Problem statement and research objective: In the Netherlands, the field norm in the ambulance sector states that at least 95% of the so-called urgent A1 calls should be reached within a 15 minutes response time. The A1 response performance was 93.7% in the Dutch province Drenthe in 2011 where emergency medical services (EMS) are only provided by UMCG ambulancezorg. This means that 6.3% of the patients in (potential) life threatening situations were not reached by an ambulance within a 15 minutes response time. Not complying with the A1 response time norm is not only undesirable for the patients involved, it can also damage the reputation of the EMS provider. Therefore the objective of this research is to suggest an EMS design that meets the 95% 15 minutes response time performance target of A1-priority calls for UMCG ambulancezorg in the region Drenthe at minimum costs for alternative demand scenarios. This EMS design consists of the locations of the stations, the resource schedule including staff, and the planning and control of ambulances.

Research step plan: With the aid of literature there are four key logistic design parameters identified. These are: the location and number of stations, the EMS resource schedule, dispatching policies and relocation strategy. The dispatching policies consist of which vehicle to send to which call, while a relocation strategy allows for relocating available units in order to cover specific areas. These design parameters play a central role in this research and form the foundation of the research step plan which contains the following steps:

1. Describe current system design based on the four logistic design parameters
2. Analyse performance; this step consists of two stages:
    a. The current performance is observed by location, time and time and location
    b. The observed performance is linked to the four design parameters to identify possible causes of low performance.
3. Redesign system and evaluate; this step consists of four stages:
    a. Alternative settings for the logistic design parameters are developed to solve the identified causes in step 2.
    b. These solutions are simulated using discrete event simulation in order to evaluate their effect on the performance of the EMS system
    c. The most effective and cost-efficient solutions are combined and simulated to find a design that met the 95% A1 response target.
    d. Three cost-efficient designs that achieved the A1 response target are chosen for further analysis
4. Test different designs for future demand scenarios; this step consists of two stages:
    a. Define future demand scenarios; different future demand scenarios are constructed by a) increasing EMS demand based on population forecast, b) closing down emergency departments of hospitals.
    b. Compare different designs; different types of solutions are modelled using discrete event simulation for different future scenarios

Results: The main findings from steps 2 to 4 from the research step plan.
The performance analysis shows that the response performance in percentages is relatively higher in the cities. However, due to the large number of calls these cities still offer the most room for improvement. The response performance in the more rural areas is significantly

lower than the cities. However, due to the low number of calls these areas offer less potential for improvement.
The same reasoning applies for the difference between days and nights. The response performance at daytime is higher than at night. However, due to the large number of calls at daytime there is still the most room for improvement at daytime. Besides these general observations, there was found to be a small dip in the A1 performance between 17:00 and 18:00.
A feasibility test shows that ambulances are not able to reach a large rural part in the centre of Drenthe within 12 minutes driving time. This largely explains the low A1 response performance in the centre of Drenthe. Except for this rural area, the location of calls with a response time over 15 minutes are often well within the reach of the nearest base. However, since areas are often covered by just one or two vehicles, situations arise when the nearest vehicle is not available and a vehicle form a more distant station is sent. This is the main reason for calls to have a response time over 15 minutes. The dip in the performance between 17:00 and 18:00 can be explained by ending dayshifts at 17:00.

By using discrete event simulation to evaluate different redesigns it was found that:

- Moving a station to a location near a highway in order to provide coverage for the working area of another station can improve the A1 response performance up to 0.44%.
- EMS resource schedule: an additional solo can improve the A1 response performance up to 0.25%.
- Dispatching policies: consistently using reroute-enabled dispatching can improve the response performance up to 1.28%. That is, always reassign an ALS vehicle to an A1 call when it was on his way to a lower priority call and it is the closest unit.
- Relocation strategy: using a relocation strategy to cover the larger places from 08:00-23:00 can improve the A1 response time by 0.97%.

Three types of solutions were developed by making combinations of single changes to the EMS system. All three types of solutions resulted in a design that was able to meet the A1 response performance objective. These solutions have a significantly higher A1 response performance and improve the current A1 response performance by more than 2.5%. Furthermore, these solutions also improved the average A1 response time by 27 seconds.

All three types of solutions and the current EMS design were tested for the impact of increasing EMS demand and closing down emergency departments on the A1 response performance. The A1 response performance for all three solutions was found to be very similar for different future demand scenarios. A small growth in demand for the year 2012 (2-4%) has almost no effect on the A1 response performance. This is not strange, since the utilization of different vehicles remains low. For larger growth in EMS demand, the A1 response performance decreases between 0.4% and 1.2% for the year 2017 and decreases between 0.8% and 2.6% for the year 2022.
Closing down emergency departments negatively affects the A1 response performance for all three solutions between 0.4% (closing down 5 EDs) and 1.5% (closing down 10 EDs). For all three solutions the drop in A1 response performance was less than for the current EMS design under different future scenarios. Therefore these three solutions are more robust than the current EMS system.

Conclusions and recommendations: In general, in order to improve the A1 response time performance in a cost-efficient way, it is very important to cover the areas where the probability of an A1 deployment is the highest. This is true, because these areas are more likely to create calls that exceed the response time norm. A cost-efficient way to do this is either by moving stations to provide multiple coverage for high demand areas or using a relocation strategy. The downside of this cost-efficient approach is that the A1 response performance in the more rural areas will decline. This is the trade-off between rural and non-rural areas.
Three types of solutions are designed. For the current situation it is recommended that solution 1 or 2 will be implemented since solution 3 is more expensive.
Solution 1:

1. Consistently use reroute-enabled dispatching.
2. Move stations to highways in order to provide coverage for areas with high arrival rates.
    a. Move base Hoogeveen to Hoogeveen Krakeel north (A37 exit 1 north)
    b. Move base Coevorden to Dalen (N854/N34 west)
3. Use a relocation strategy to cover Emmen, Assen, Hoogeveen, Meppel, Tynaarlo, and Coevorden between 08:00 and 23:00 in that order.

Solution 2: Consists of points 1 and 2 from solution 1, and in addition:

3. Move base Klazienaveen to Nieuw Amsterdam (A37 exit 5 south)
4. Place additional capacity in Tynaarlo in the evenings and weekends. A solo is preferred because a solo is more cost-efficient than an ALS vehicle.

The additional yearly costs of both solutions are around €120.000. This consists of personnel costs and the costs of additional kilometres by the relocation strategy. This costs calculation does not include the costs of finding a new location for the bases. When total EMS demand will increase by more than 10% or multiple emergency departments will close, these solutions do not obtain the A1 response performance objective. Therefore, neither of these solutions will achieve the response performance target in the year 2017. Further research is required to design cost-efficient solutions in these cases. The step plan of this research can be used in developing such solutions. This step plan will ensure a structured process for analysing the performance and designing solutions for the identified problems.

FOREWORD AND ACKNOWLEDGEMENTS

This master thesis is the last piece of work towards graduating my study Industrial Engineering and Management. I executed this research at UMCG ambulancezorg, a company that provides emergency medical or ambulance services in the region Drenthe. During the six months that I was working on this project I have found that it is an interesting and rapidly developing world where the uncertainty of events creates a kind of all-or-nothing situation. With the picture on the cover of this thesis, I like to grasp the dynamic aspects of this healthcare world. The picture displays an ambulance that is travelling with lights and sirens. However, the shutter speed of the camera was very long, creating a blur of the lights of the ambulance.

There are a few people I would like to thank for making it possible to write this thesis. First of all I would like to thank my first and second supervisor Durk Jouke van der Zee and Kees Jan Roodbergen. Especially the meetings with Durk-Jouke were fruitful and inspiring. He always took a lot of time for me to discuss the progress of this research and helped me structuring the work. For this I am grateful.

Secondly, I would like to thank my supervisor Jaap Hatenboer at UMCG ambulancezorg. Jaap is a person with vision and he gave me a lot of reading material and new insights into the world of healthcare. Special thanks go to Harriëtte Holt of UMCG ambulancezorg. Although she was not a formal supervisor in this project, she has helped me a great deal by familiarizing me with the emergency medical services world. I enjoyed working with her and learning from each other.

My final thanks goes out to my family, friends and girlfriend. They always supported me and encouraged me to do my best.

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GLOSSARY

A1 deployment: an emergency deployment with A1 priority assigned by the dispatcher in the control centre in case of direct threat of the vital functions of the patient or when this threat can only be excluded after examination by the ambulance team at the scene. The ambulance team should be as soon as possible at the scene and may make use of lights and siren. 95% of the A1 calls should be within a 15 minutes response time.

A2 deployment: an emergency deployment with A2 priority assigned by the dispatcher in the control centre in response to a request for help when there is no immediate life danger, but there can be (serious) health damage and the ambulance team should be as soon as possible at the scene. 95% of the A2 calls should be within a 30 minutes response time.

Ambulance: an ambulance is a vehicle that is used for providing emergency medical services, which is specially designed for transporting and providing medical care for patients. There are two main types of ambulances:

- ALS ambulances; advanced life support ambulances. These ambulances are usually staffed with higher skilled personnel than BLS ambulances and respond to urgent emergency calls.
- BLS ambulances; basic life support ambulances. These vehicles are usually staffed with paramedics. These vehicles are sent to non-critical calls where transport is required.

Ambulance team: the ambulance team consists of a registered nurse and a dedicated driver.

B deployment: a deployment with B priority assigned by the operator in the operating room in response to a request for help without A1 or A2 priority, wherefore a time or time interval is agreed upon to pick up or bring a patient. UMCG ambulancezorg also differentiates between B1 and B2 priority deployments, for the former there is some health risk involved and an ALS ambulance with a registered nurse is required.

Call: a call is an emergency event to which an emergency vehicle responds.

Rapid responder: a rapid responder, for example a motor, may consist of an ALS provider which can initiate the treatment and triage the level of additional response needed. They cannot transport a patient; the focus here is on getting a high-level provider at the scene quickly, rather than a transport vehicle.

Response target: a response target is a defined performance measurement that an emergency service must meet. See A1- and A2-deployment for the specific targets in Dutch EMS systems.

Voorwaardescheppende rit: a deployment assigned by the dispatcher in the control centre whereby the ambulance team is relocated to a certain location chosen by the dispatcher in order to insure the availability of emergency medical services.

Activation input: the activation input time is the time it takes from the moment the phone is picked up at the control centre until the moment the dispatcher assigns a vehicle to the call.

Mobilisation duration: the mobilisation duration is the time it takes from the moment the vehicle is assigned to the call until the moment the wheels of the ambulance start spinning.

Mobile Medical Team: a MMT consists of a specialised physician, a specialised nurse and a dedicated driver or pilot. The MMT provides on-site specialised acute medical care to victims of serious accidents and disasters. The MMT is coupled to a trauma centre. The provided care is an addition to the regular emergency medical services.

Travel to scene time: the travel to scene time is the time it takes from the moment the wheels of the ambulance start spinning until the moment the ambulance arrives as close as possible at the scene where the patient is located.

Response time: the response time is the time it takes from the moment the phone is picked up at the control centre until the moment the ambulance arrives as close as possible at the scene where the patient is located.

LIST OF ABBREVIATIONS

ALS	Advanced Life Support
AZN	Ambulancezorg Nederland
BLS	Basic Life Support
DAM	Dynamisch Ambulancemanagement
ED	Emergency Department
EMS	Emergency Medical Services
MKNN	Meldkamer Noord-Nederland
MMT	Mobile Medical Team
RAV	Regionale Ambulancevoorziening
SEH	Spoedeisende Hulp
TWaz	Tijdelijke Wet ambulancezorg
UMCG	Universitair Medisch Centrum Groningen
vws rit	Voorwaardescheppende rit
VWS	Volksgezondheid, Welzijn en Sport (Ministry of Health)
Wav	Wet ambulancevoorziening

1. INTRODUCTION


Figure 1 The Star of Life

We have all seen the star of life on the side of an ambulance; the star that internationally represents emergency medical units and personnel. The star is outlined with a white border with the rod of Asclepius in the middle. Each of the six points of the star represents an aspect of the Emergency Medical Services (EMS) system:

1. Early detection
2. Early reporting
3. Early response
4. Good on-scene care
5. Care in transit
6. Transfer to definitive care

This symbol is also visible on the ambulances in the Northern Province Drenthe in the Netherlands. These ambulances are the property of UMCG ambulancezorg which is the only provider of ambulance services or EMS in Drenthe.

1.1 Company description

UMCG ambulancezorg is a 100% autonomous daughter company of Universitair Medisch Centrum Groningen (UMCG).
The principles of the organization are:

- the provided care should meet the needs of the care recipient as close as possible;
- the provided care should contribute to the quality of the life of the care recipient as much as possible;
- health system is a shared responsibility of the patient and the care provider and
- the available budget is used as efficient as possible to provide care.

Table 1 provides an overview of the number of nurses, ambulance drivers, dispatchers and supporting staff at UMCG ambulancezorg. An organogram of the company can be found in Appendix A.

Table 1 Employees of UMCG ambulancezorg

Number of registered nurses	85.06 FTE
Number of ambulance drivers	72.61 FTE
Number of dispatchers	11.39 FTE
Number of miscellaneous employees	38.74 FTE

In order to fulfil the principles of the organisation, UMCG ambulancezorg operates from 13 different ambulance stations in Drenthe. The following ambulances are operational to provide care on a normal weekday:

- 18 Advance Life Support (ALS) ambulances (for urgent calls)
- 4 Basic Life Support ambulances (for planned transport)
- 2 solo ambulances (a smaller vehicle with only one nurse, not used for transport)
- 1 motor ambulance (one nurse, not used for transport)

Together, these vehicles served over 35.000 urgent and non-urgent medical calls in 2011.

1.2 Developments in the Dutch EMS

In 1971, the Dutch Government passed the 'Wet Ambulancevervoer' (Wav). This law regulated the supply of ambulance services, who controls the ambulances, who is allowed to provide ambulance services, and how it is financed. In 2012, this law is replaced by a new law 'Tijdelijke wet ambulancezorg' (TWaz). In this new legislation the health insurers obtain a more central role. The Ministry of Health (VWS) will issue permits for a period of five years. In deciding which organisations receive a permit, the opinion of health insurers will be heavily weighted. The emergency medical services will be organised regionally where each safety region in the Netherlands will have one EMS supplier. In the North, these safety regions are the same as the provinces. Since UMCG ambulancezorg is the only provider of EMS in Drenthe, this legislation does not change the EMS system in Drenthe. However, since the opinion of health insurers is heavily weighted, they obtain more power and have a strong voice in the viability of particular EMS suppliers. In order to survive, the performance of EMS suppliers will be more important. The third point of the star: 'early response' is particularly important for measuring the performance of Dutch EMS systems.

Besides new legislation there are other developments that have an impact on EMS. These developments can be divided into two scenario categories:

- Autonomous growth in EMS demand
- Restructuring the health care system

Autonomous growth in EMS demand is largely determined by demographic developments. Demand for EMS depends for a part on the population size and ageing of people. In general, older people need more healthcare and more often request an ambulance. It is expected that the total population in Drenthe will remain fairly constant in the next 10 years. However, the percentage of people above 65 years in Drenthe will increase from 17.8% in 2010 to 23.4% in 2020. (Provinciale staten van Drenthe, 2012) This will result in higher demand for EMS.

Since EMS is part of a healthcare chain, developments in the medical world can have an impact on the EMS system. Mergers of hospitals, closing down emergency departments (ED), and taking more urgent calls from general practitioners are possible developments that affect the EMS system in multiple ways. These organisational restructurings in the health care system can result in additional demand for EMS, but can also increase transport times when the nearest hospital is no longer suitable for the transported patient.

1.3 Structure of the report

The structure of the report is as follows:

Chapter 2 discusses the research design where the research problem is defined and the objectives of this study are presented. This chapter also presents a step plan for the remainder of this research.

Chapter 3 provides an overview of relevant literature which serves as a foundation for the remainder of this report.

The research step plan of chapter 2 followed in chapters 4-7 where after conclusions and recommendations are presented in chapter 8.

Chapter 9 provides a reflection on the research.

2. RESEARCH DESIGN

This chapter presents the research design. In section 2.1 the problem is explained. A problem and stakeholder analysis can be found in Appendix B and C respectively. Section 2.2 contains the problem definition. After the problem is defined, a conceptual model is created which provides a complete overview of the object of research. This conceptual model with their different concepts is elaborated in section 2.3. The performance indicators in this research are addressed in section 2.4. Based on the conceptual model a number of research questions were constructed (section 2.5). At last, a detailed research step plan is presented which also explains the used research methods for each research question of section 2.5.

2.1 Problem context

In the Netherlands, there is a strongly professionalised emergency medical service (EMS) system. When there is an acute emergency, a national emergency number can be called. When an ambulance is requested, the call is reconnected to a nurse in a regional control centre. This nurse assigns a priority to the call if necessary. After a priority has been assigned to the call, a dispatcher assigns an ambulance to the call. The most urgent calls are assigned with an A1-priority. These A1 calls concern (potential) life-threatening situations for which the nurse in the control centre has decided that an ambulance team should be at the scene as soon as possible.

In the Netherlands, there are a few response time field standards EMS systems should satisfy. From these standards there is particular political and public attention for the 15 minutes response time target for urgent A1 calls. This norm states that at least 95% of the urgent A1 calls should be reached within 15 minutes. A secondary norm states that 95% of the less critical A2 calls should be reached within 30 minutes. Besides these response norms, patients should be able to reach a hospital within 45 minutes from the moment the call is received.

In the Netherlands there are 25 different RAV-regions (regionale ambulancevoorziening) which all cover a specific region. The available budget for these different regions is for a part determined by the so called national coverage and availability framework (=Landelijke Spreiding en Beschikbaarheidkader) (RIVM, 2008). The foundation for this framework is based on two computational models wherein the locations and number of ambulances is calculated. The purpose of this framework is to provide the EMS systems in the different regions with the necessary budget in order to satisfy the field standard of serving 95% of the A1 emergency calls within a 15 minutes response time.

2.1.1 Current A1 response performance

The initial problem owner in this research is Jaap Hatenboer, vice-president at UMCG ambulancezorg. He concluded that although the national coverage and availability framework is followed, this field standard is not achieved in the region Drenthe were EMS are provided by UMCG ambulancezorg. In the years 2008, 2009, 2010, and 2012 the performance on this 15 minutes response time target has been 93.9%, 93.6%, 91.8%, 93,7% respectively. In most occasions, not achieving this target can be attributed to a long travel to scene time. In most cases when the target is not achieved the ambulance departs from its assigned base and the scene is just too far away from the base or the scene is outside the own working area of the assigned ambulance. This cause can be related to the location, availability and distribution of resources across the region. Therefore in order to tackle this problem it must be investigated whether the EMS system, that is, the use of the current resources, (i.e. stations, vehicles, staff and the planning and control) can be reorganised in a way to achieve the 95% response performance for A1-priority calls. Besides making effective use of the current resources, the EMS system should also be cost-efficient.

2.1.2 Consequences of not achieving the A1 response performance target

The performance of a particular EMS system is important for the different patients but also for the EMS provider itself.

Patients want to be treated as soon as possible. When the response time target is not achieved this means that patients in (potential) life-threatening situations have to wait more than 15 minutes before the ambulance team is on the scene. Longer waiting times for patients are considered to be undesirable and may result in a negative effect on the survival rate and physical mobility of patients.

Besides the interest of the patient, UMCG ambulancezorg benefits from a better response performance. Low response performance may damage the reputation of UMCG ambulancezorg. There is also political pressure on achieving this 15 minutes response time target and complying with the standard of a maximum 45 minutes to reach a hospital. Due to new legislation (TWaz) as mentioned in chapter 1, underperformance may result in a loss of licence for supplying EMS. Therefore, not obtaining the response target can seriously threaten the long-term viability of UMCG ambulancezorg.

2.1.3 Developments that have an impact on demand for EMS

Besides the current issue of not achieving the 15 minutes A1 response time target, there are autonomous growth scenarios and (possible) healthcare organisation scenarios that may impose additional pressure on the performance of the EMS system in Drenthe. Most important examples are:

- Demographic developments: the size of the population and the aging of people
- Closing down Emergency Departments (EDs)
- New triage systems in the control centre
- Specialisation of hospitals
- Taking over urgent calls from general practitioners

The examples above may result in a higher demand for EMS, a different demand mix for EMS, or longer driving distances for the ambulances and thereby reducing the availability of the resources in Drenthe. This additional demand can put more strain on the current resources and may have a significant effect on the performance of the EMS system.

2.2 Problem definition

The problem context described two general problems. The first problem is related to the current issue of not achieving the response target performance for A1-priority calls. The second, more long-term, problem demands more insight into the system regarding different possible scenarios which have an effect on demand or performance of EMS.

Therefore the research objective is:
To suggest an EMS design that meets the 95% 15 minutes response time performance target of A1-priority calls for UMCG ambulancezorg in the region Drenthe at minimum costs for alternative demand scenarios.

Research question:
In what way can the response performance of A1 emergency calls be improved by redesigning the EMS system for the current and possible future scenarios?

Boundary conditions
- The research is conducted by Mr R.A. van Werven, a master student industrial Engineering & Management from the University of Groningen.
- Guideline, protocols and procedures of UMCG ambulancezorg should be followed.
- The research should be completed within six months.

2.3 Conceptual model

In order to provide a clear picture of the system a conceptual model (CM) is constructed. The CM is presented in Figure 2 and consists of the following aspects:
1) The input into the EMS system
2) The environment which affects the input into the EMS system
3) The EMS system with their design parameters addressed in this research
4) The output of the EMS system
5) The performance measurements of the EMS system

The input consists of demand for EMS based on the characteristics of the patient. The dashed line connecting Environment with Input indicates that this input is influenced by different developments in the environment. The EMS system itself can be described by four parameters which determine the logistic setup of the EMS system. These four parameters are elaborated in chapter 3. The output of the system consists of patients which are treated and/or transported. The important performance indicators; the A1 response performance and costs of the EMS system are influenced by the network setup of the EMS system.

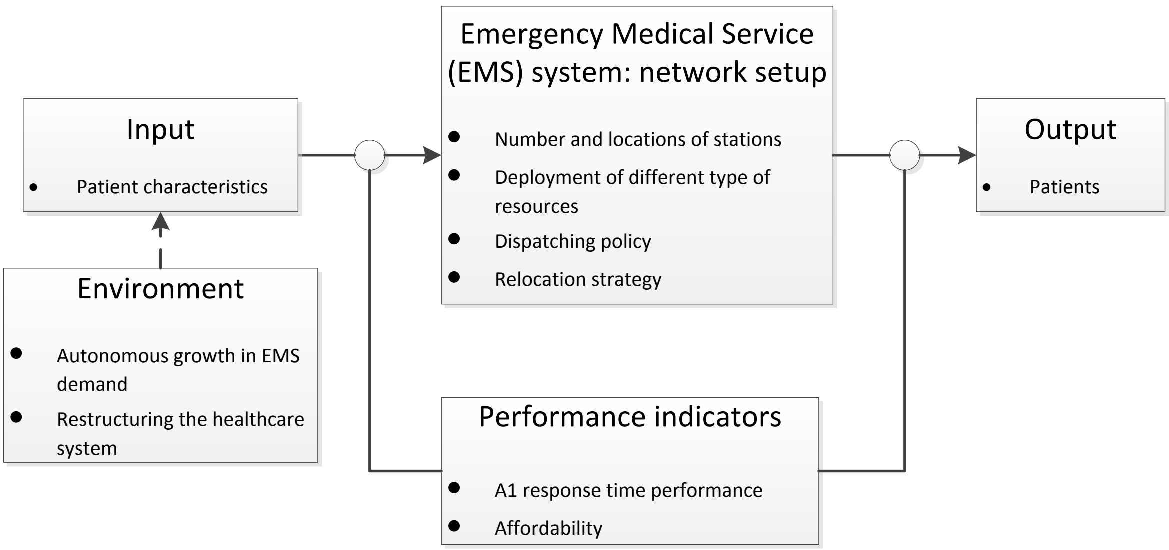


Figure 2 Conceptual model

2.4 Performance indicators

There are two primary performance indicators in this research. The most important performance indicator is the A1 response performance. The aim is to achieve a 95% A1 response performance at minimum costs. That is, reaching at least 95% of the A1 calls within a 15 minutes response time. In reality there is a budget that limits the available resources. In this research it is assumed that there is no restriction on the available resources. However, at minimum costs automatically means that a design within the available budget is preferred to a costlier design. The obtained A1 response performance is however leading in this research. The A1 response performance and the affordability of the EMS system are addressed below.

A1 response performance

The central performance indicator in this research is the response performance of A1-priority calls. The A1 response performance is defined as:

$$A1\ response\ performance = \frac{Number\ of\ A1\ calls\ within\ 15\ minutes\ response\ time}{Total\ number\ of\ A1\ calls} * 100\% \quad \text{(Eq. 2.1)}$$

This 15 minutes response time can be broken down into three time segments for an ambulance idle at its station:

- ‘Activation Input’ (Call received to Dispatch),
- ´Mobilisation Duration´ (Dispatch to Mobilised), and
- ‘Travel to Scene’ (Mobilised to Arrival)

The activation input consists of talking on the phone and assigning an ambulance to the call. The control centre is responsible for this part of the process. The target is to keep the activation input under 2 minutes.

The mobilisation duration is the time it takes for an ambulance team from the moment they are dispatched by the control centre until the ambulance proceeds towards the scene. The standard is 1 minute at daytime and 2 minutes at night. In Drenthe there has already been put considerable effort into reducing this time segment in the last couple of years. National comparison shows that Drenthe is actually performing quite well on this time segment (0:46 min average Drenthe, 1:46 min average Netherlands. (AZN, 2011)

The travel to scene time makes up the largest part of the response time. The standard for this time segment is a maximum of 12 minutes at daytime and 11 minutes at night. Note that calls with a response time over 15 minutes can exceed multiple time segments.

Affordability

For the second performance indicator the narrow definition of costs is used; i.e. the financial operational costs of the EMS system. UMCG ambulancezorg works with a budget provided by the Insurance Company. The available budget is calculated based on a national coverage and availability framework. This budget is not completely static. UMCG ambulancezorg can negotiate additional funding for their EMS system in Drenthe.

It is preferred that the costs stay within the available budget. However, the A1 response performance is leading in this research. The available budget is therefore not a restriction in this research. This means that the operational costs may exceed the available budget. The operational costs are calculated by summing the yearly costs of the stations, vehicles and employees.

2.5 Research questions

Based on the different concepts in the conceptual model the following research questions are constructed:

1. In what way can the performance of EMS systems be measured and what are the key logistic design parameters of EMS systems? (Chapter 3)
2. How can the current EMS system be characterised? (Chapter 4)
3. What is the performance of the current EMS system and how can this performance be explained? (Chapter 5)
4. What are the possibilities for redesigning the EMS system in order to improve the A1 response performance in a cost-efficient way? (Chapter 6)
5. What is the effect of relevant future demand scenarios on the response performance of different EMS designs?

2.6 Research step plan

This section has two purposes: firstly, it proposes a step wise approach for executing this research. Secondly, it details each step by highlighting the research activities that are used in this research.

The first research question: “In what way can the performance of EMS systems be measured and what are the key logistic design parameters of EMS systems?” is answered with the aid of a literature review in chapter 3. This chapter serves as a foundation for the research step plan and therefore for the remainder of this research. In chapter 3 different performance indicators are reviewed. Key logistic design parameters are identified and classified based on the planning horizon and costs involved for changing that parameter.

After relevant literature has been reviewed, the following step plan is followed based on the research questions of section 2.5. The first step of the research step plan corresponds to the second research question while the second step of the research step plan corresponds to the third research question etc. Figure 3 presents the research step plan.

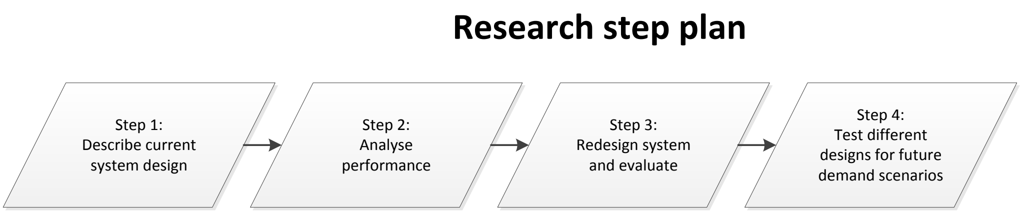


Figure 3 Research step plan

Step 1: Describe current system design (chapter 4)

The first step in the process is to describe the current system in terms of the key logistic design parameters as identified in chapter 3. It thereby answers the second research question: “How can the current EMS system be characterised?” The current EMS system will be described based on interviews, documentations, and analysis of empirical data from UMCG ambulancezorg.

The description of the current EMS design consists of a description of the control centre (section 4.1), A1 priority calls (section 4.2), and the ambulance team with their resources (section 4.3). An overview of the current interpretation of the key logistic design parameters is presented in section 4.4.

Step 2: Analyse performance (chapter 5)
After the current system is described, the current performance is analysed. This step therefore answers the research question: "What is the performance of the current EMS system and how can this performance be explained?"
The analysis consists of a two-stage approach:
- First the current performance is observed by location, time and time and location.
- Secondly, a cause and effect analysis is performed in order to explain the performance based on the key logistic design parameters.

For every deployment all kind of data is registered like the date, location and different time segments of the deployment. Based on data from UMCG ambulancezorg Drenthe from 2010 and 2011, the A1 response performance is analysed by location, time, and location and time (section 5.2). Weak areas and/or day segments are identified. Possible cause and effect relationships between key logistic design parameters of the EMS system and the A1 response performance are determined by deterministic methods and findings from literature (section 5.3). The impact of different causes on the A1 response performance is made quantifiable by deterministic methods. The main findings are summarised in section 5.4.

Step 3: Redesign system and evaluate (chapter 6)
In step 2, a number of causes that contribute to the problem were identified. In this step, alternative settings for the key logistics design parameters are developed that solve the identified causes from step 2. This is done with the aid of literature and expert knowledge. It thereby answers the fourth research question: "What are the possibilities for redesigning the EMS system in order to improve the A1 response performance in a cost-efficient way?"
Discrete event simulation is chosen as a tool to test different solutions for the identified causes. The simulation model is validated by comparing the outcomes of the model to the historic A1 response performance.
The specific approach taken to redesign and evaluate alternative EMS designs consists of four stages:
- Adaptations to the key logistics design parameters are developed to solve the identified causes of section 5.4 with the aid of literature and expert knowledge. (section 6.1)
- Round 1 of scenarios: these solutions are modelled, simulated and evaluated to determine their impact on the A1 response performance. (section 6.3)
- Round 2 of scenarios: effective and cost-efficient solutions are selected from round 1. These solutions are combined, modelled, simulated and evaluated with respect to the A1 response performance and costs of the design. (section 6.4)
- Three different designs that fulfil the performance objectives of this research are evaluated in more detail. (section 6.5)

The main findings from this chapter are summarized in section 6.6.

Step 4: Test different designs for future demand scenarios (chapter 7)
The final step of this research step plan consists of an analysis of the response performance of the current and three different redesigns (chosen in step 3) for future demand scenarios. This step addresses the fifth research question: "What is the effect of relevant future demand scenarios on the response performance of different EMS designs?"
This step consists of two parts:

- First, relevant future scenarios are constructed (section 7.1).
- Secondly, the current and three chosen EMS designs from step 3 are simulated and evaluated for the relevant future scenarios (section 7.2)

EMS demand is not constant over the years. Therefore it is interesting to see how a change in demand affects the A1 response performance of the EMS system. In this research there is chosen to create different future scenarios based on autonomous growth in EMS demand scenarios (section 7.1.1) and restructuring the healthcare system scenarios (section 7.1.2).

Data from UMCG ambulancezorg and a population forecast from the province Drenthe are used to construct different possible demand growth scenarios. These scenarios are developed by determining the need for EMS per 1000 inhabitants for different age categories. A population forecast differentiated by age category is used to calculate the resulting EMS demand. Since not all growth in EMS demand is explained by demographic factors, future demand is also calculated for an increase in the utilization per 1000 inhabitants per age category.

For restructuring the healthcare system we will look at closing down emergency departments. The Danish Health Council presented a report with advice on how to structure the hospitals in Denmark. Based on guidelines from this Danish Health Council report, different emergency department scenarios are developed for Northern Netherlands.

With discrete event simulation the A1 response performance for the current EMS system and the three different designs chosen in step 3 is quantified and evaluated (section 7.2). Main findings from this step are summarized in section 7.3

3. EMERGENCY MEDICAL SERVICE SYSTEMS DESIGN

This chapter addresses the first research question: “In what way can the performance of EMS systems be measured and what are the logistic design parameters of EMS systems?”

In order to answer this research question *Web of Science* and *PubMed* were used for an online literature search. The following keywords were used: [emergency medical service OR EMS OR ambulance] AND [model OR performance OR simulation OR framework OR review OR system] AND [location OR relocation OR allocation OR dispatching OR staffing OR response]. The focus in this search was on review articles. Through cross reference searches other relevant articles were identified. The first selection of articles was made on words in the title and the abstract. Relevant literature was read in full. Articles that did not describe relevant logistic parameters or the performance of EMS systems were excluded.
Section 3.1 addresses the first part of the research question: In what way can the performance of EMS systems be measured?
Section 3.2 addresses the second part of this research question: What are the key logistic design parameters of EMS systems? There are four design parameters identified and elaborated. These four design parameters are classified based on the planning horizon and costs involved to changing these parameters.
Chapter 3 is summarized in section 3.3.

3.1 Performance framework and measurement of EMS systems

This section addresses the first part of the first research question: ‘In what way can the performance of EMS systems be measured?’
First a general performance framework is presented. (Section 3.1.1) Two performance indicators that are relevant for this research are reviewed in section 3.1.2.

3.1.1 Performance Framework

The performance of Dutch ambulance services is a relevant issue for the public and in politics. However, performance is a vague concept which can be measured in a number of different ways. Although there has been made considerable effort to develop, collect and analyse performance indicators, there are few universally accepted methods of measurement. This is partly caused by the fact that there are few validated indicators of effectiveness and quality in ambulance systems or emergency medical service systems. (Guppy and Woollard, 2000) Performance can relate to response times, but it can also relate to satisfaction of the customer or costs effectiveness of the organisation. The type of relevant performance measurement depends on whether the structure, process or outcomes of the organisation is the object of analysis. (O’Meara, 2005)
O’Meara developed a potential framework for ambulance services with eight different dimensions based on these three types of data (Structures, Processes and Outcomes). This framework is presented in Table 2.

Table 2 Potential Performance Framework for EMS systems with relevant performance indicators (O'Meara, 2005)

Dimensions	Structures	Processes	Outcomes	Description
Effectiveness	Equipment Staff skills	Response times Resuscitations Interventions	Mortality Survival	Care/service, intervention or action achieves desired results.
Appropriateness	Staff configuration Staff level Evidence base	Research activities Time at scene	New knowledge Adverse events	Care/service provided is relevant to client/patient needs and based on established standards
Safety	Monitoring system	Safety procedures Quality of care	Accreditation Complications	Potential risk of an intervention or the environment are avoided or minimized
Capability	Appropriate staff Equipment	Clinical practice guidelines and standards Preparedness for disaster	Impaired physiology Alleviation of discomfort	Individuals knowledge/skills are appropriate to care/service provided.
Continuity	Sustainability Teamwork	Coordination Collaboration	Limitation of disability Accurate information	Ability to provided uninterrupted, coordinated care/service across programs, practitioners, organizations, and levels of care/service, over time.
Accessibility & Equity	Time to cases Distance to cases	Resource allocation processes	Utilization rates Availability Demand for services	Ability of client/patients to obtain care/service at the right place and time, based on needs and is equitable.
Acceptability	Public participation Ethical standards	Respect for patient autonomy Accountability	Satisfaction Complaints	Care/service provided meets expectations of client, community, providers and paying organizations.
Efficiency	Staff to case ratios	Rostering systems	Affordability Cost-effectiveness	Achieving desired results with most cost-effective use of resources.

From this potential performance framework it is clear that there are many possible performance indicators. The focus in Dutch EMS, and therefore in this research, is on the logistical performance indicator response times. Since there are budgets for what EMS may costs, affordability of the EMS is also taken into account. These two primary PIs are marked red. Factors from the dimension *Accessibility & Equity* are also considered to be important from a logistical perspective. These factors can be used to identify reasons for failure to meet objectives.
Response times and affordability are only parts of the two dimensions *Effectiveness* and *Efficiency;* this means that other dimensions (*Appropriateness*, *Safety*, *Capability, Continuity, and Acceptability*) of the performance of an EMS system are not addressed at all. Also the quality of the provided care, not explicitly mentioned in the framework above, will not be addressed. This means that clinical performance indicators that address the quality of the provided care are not considered. For a review of clinical performance indicators for measuring quality in EMS, the reader is referred to Sayed (2011) and references therein. Unlike Dutch EMS systems, EMS systems in the UK, Australia and USA have been developing clinical performance indicators. It is expected that this trend will spread to the Netherlands.
For now, the response time is the only performance indicator in Dutch EMS systems. Response times and affordability are reviewed in section 3.1.2.

3.1.2 Primary performance indicators

Response times

In general, emergency medical services have the objective to respond to calls for assistance as quickly as possible to reduce loss of life and injury. To determine the effectiveness of the system, an analyst ideally wants to focus on outcomes like lives lost. However, many deployments studies have focused on surrogate performance measures such as response

time. (Swersey, 1994) The question remains whether this surrogate performance indicator is correct and how it should be measured. Most research in this area is based on cardiac arrest which corresponds only to a small percentage of the calls for assistance. Different conditions demand different treatments and therefore impose other demands for the maximum response time. For more on the relationship between response time and probability of survival see Erkut, et al. (2008). Although time intervals are widely used to report on performance, there is no universally accepted chronicle time sequence of EMS response. (O'Meara, 2005) Therefore, different countries use different response performance targets based on their own results from the past. (Spaite et al., 1993) Most standards are formulated as achieving a percentage *p* of all calls having a response time under Δ minutes. In the Netherlands there is chosen for a response target of achieving 95% of all A1-priority calls under 15 minutes. Some countries also make a distinction between rural and non-rural areas and have different response performance targets for these different areas. Off course there is a large difference between Dutch rural areas and for example Australian rural areas.
Related to this distinction between urban and rural areas is the balance between efficiency and equity. High efficiency gains can be obtained by focussing on high risk or non-rural areas where most of the calls for assistance occur. This focussing on high risk areas comes at the costs of performance losses in smaller towns or rural areas where calls are less likely to occur. Based on equity grounds, all resources are spread evenly across the area. (Swersey, 1994)
So although there is no universally accepted way of measuring the response time, it is a widely used and accepted performance indicator.

Affordability

Lerner et al. constructed a comprehensive framework for determining the costs of an EMS system (2007). The components, of this framework are displayed in Figure 4. If one is only interested in the operational costs of the resources, than the following aspects should be included:

- Human resources (ambulance crew)
    - Salaries
    - Overtime
- Vehicles (ambulances)
    - Acquisition
    - Operation
    - Maintenance
- Physical plant (ambulance bases)
    - Acquisition
    - Operation
    - Maintenance

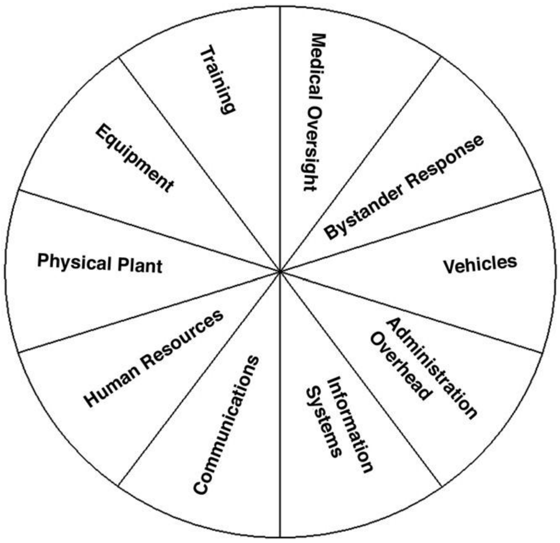


Figure 4 Cost components EMS system (Lerner et al., 2007)

Other cost components are not influenced by a different network setup of an EMS system.

3.2 Network setup of EMS systems

This section addresses the second part of the first research question: 'What are the logistic design parameters of EMS systems?' The purpose of this section is to identify relevant design

parameters of an EMS system, describe these parameters and list different alternatives for each parameter.
The design of emergency medical service systems has received much attention in the operations research literature for the past few decades. (Goldberg, 2004) The reason for this is clear since these systems are important to the public. The authorities are mainly preoccupied with the efficiency and equity of the EMS system. Like described in section 3.1 the commonly expressed objective is the satisfaction of demand within a specified response time. The precise meaning of the often vague concepts “demand”, “satisfaction”, and “response time” will determine the setup of the EMS system and thereby the necessary resources. (Trudeau, 1989)
In section 3.2.1 four different design parameters are identified that determine the setup of an EMS system. These four design parameters are elaborated and classified as being on a strategic, tactical or operational level based on the planning horizon and financial costs involved (section 3.2.2). Different alternatives for each parameter are presented in section 3.2.3.

3.2.1 Design parameters of an EMS system

The literature search as described in the beginning of this chapter resulted in many articles about EMS systems. Most articles, as also indicated by Goldberg (2004), focused on models for supporting decisions such as: locating and relocating ambulances and/or stations, the number of vehicles of different types, the staffing of ambulances and different dispatching systems. The central logistic performance indicators in this research are the response time performance and costs of the EMS system. Therefore I make a distinction in this research between four design parameters that together have an impact on the response performance and costs of the EMS system:

1. the number and locations of stations;
2. EMS resource schedule: i.e. the number of different types of vehicles to deploy at each base and at what times they should operate, including staff;
3. dispatching policies; and
4. relocation strategy: i.e. how and when to re-deploy resources under different system states.

3.2.2 Classification of design parameters

The four different design parameters identified in the former section can be classified as being on a strategic, tactical or operational level based on the estimated time horizon and amount of investment it takes to change this parameter. While strategic issues concern the more long-term direction of the company, tactical issues concern the translation of these strategic decisions into procedures. The actual day-to-day execution of these procedures is part of the operational level. The four parameters are explained and classified below. Figure 5 was developed for this research to graphically show the planning horizon and costs that are associated with changing these parameters. The resulting figure is validated by a senior policy maker from UMCG ambulancezorg.

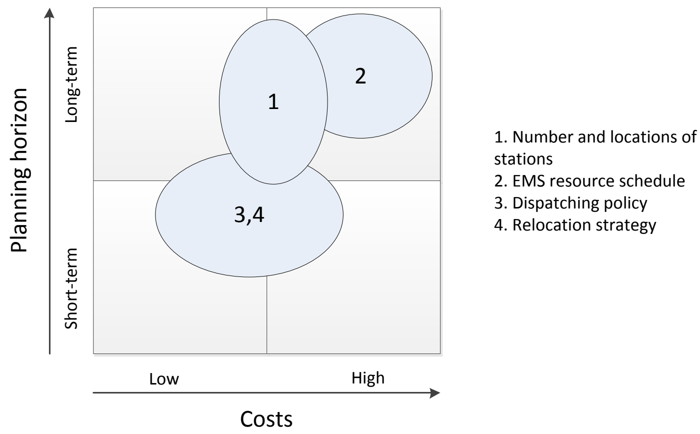


Figure 5 Classification of design parameters based on costs and planning horizon

The number and locations of stations
The number and location of the different stations depends on the objectives of the system. Usually stations are positioned to provide 'coverage' to demand points. A demand point is said to be covered by a site when the distance or travel time from the site to the demand point is smaller than some predefined time or distance limit. (Jia et al., 2005) There is a mid to long-term commitment to the number and locations of stations. Finding the right location and building a new station can take a significant amount of time. There may be substantial politics involved in deciding where to locate different stations. Building or moving a station can be very costly depending on whether it is a fixed station (costly) or a movable base (relative cheap and easy to move). However, the costs for a new station are depreciated over 50 years. Effectively, the yearly operational costs are therefore much lower than for example the salaries for personnel. This design parameter is on a strategic level and is placed in the middle of the upper segment of Figure 5.

EMS resource schedule: i.e. the number of different types of vehicles to deploy at each base and at what times they should operate, including staff
This parameter comprises the schedule of which type of vehicle should be operational on which location and on what times. For a vehicle to be operational the vehicle should be staffed with skilled employees. Therefore this parameter includes the staffing of ambulances. Personnel makes up the most costs of an EMS system and it takes time to skill paramedics. The time and costs involved to create additional shifts makes it difficult to change the EMS resource schedule. Although small adjustments to the shift schedule can be made rather quickly without high costs, most changes have a significant impact on the yearly operational costs. This design parameter is therefore also on a strategic level and is placed in the upper right corner of Figure 5.

Dispatching policies
The decision of which vehicle to send to which call is a daily decision the dispatcher in the control centre faces. Therefore the daily execution of the dispatching policies is part of the operational level. However, the procedures the dispatchers should follow can be regarded as on a tactical level. These procedures do not change on a daily basis because changing these policies can have substantial effect on the performance of the EMS system. Depending on the degree of change in policy there can be short to mid-term planning horizon and the costs can be low or high. This depends on whether new systems should be purchased and whether

or not personnel should be reskilled. Therefore the dispatching policy is located in a large oval a bit to the lower left corner of the middle in Figure 5.

Relocation strategy: i.e. how and when to re-deploy resources under different system states. In aspect two, the location of ambulances referred to the static location or allocation of units to provide certain coverage in order to respond quickly to emergencies. However, real EMS systems are dynamical systems which change throughout the day. As ambulances are dispatched to emergency sites, they become busy and cannot serve other calls. Therefore areas may become left uncovered when all units in that area are busy serving calls. When a new call occurs in this area, there may be no available unit to respond to this call within the response time. However, at the same time there may be other ambulances idle at their own station. Redeployment of available units may prevent this situation and provide better coverage for a certain time period.
This parameter is similar to the dispatching policy: relocating units is a daily decision, but the specific procedures the dispatcher should follow can be regarded as on a tactical level. Depending on the nature of the modification of the relocation strategy, there can be a short to mid-term commitment to these policies. The costs can also be low or high depending on whether dispatchers should be retrained to get familiar with the new procedures or systems. Relocation strategy is also positioned a bit to the lower left corner of the middle of Figure 5.

3.2.3 Alternative choices for the design parameters

This section addresses important issues and supporting models for the four identified design parameters and list alternatives for each parameter where possible.

Number and location of stations (1/4)

There are literarily thousands of possible locations to locate emergency facilities. Adapted from Marianov and ReVelle (1995) there are a number of questions and issues that should be addressed to decide on the spatial location of sites. By answering these questions, boundary conditions can be set which can be used as an input for specific location models. The questions are presented in Table 3. Different models are addressed below.

Table 3 Issues to address when deciding where to locate emergency facilities

Question	Elaboration
How much coverage should the EMS system provide?	If there are no budget constraints, the objective might be to provide coverage for the entire population. However, this objective conflicts with the objective of minimizing the costs of the system.
How long can customers involved in an emergency afford to wait for service before the consequences of a lack of response become intolerable?	The shorter the demanded response times, the more resources are necessary which leads to increased costs.
What does coverage, or good quality coverage mean?	This issue addresses the question whether demand points should be covered by multiple vehicles/bases.
Is there any interaction with other systems?	This question addresses the issue of whether there are any other services that can fill in the spot when a timely ambulance response is impossible?
Is it politically feasible to close or relocate some locations?	Closing a station that provided a sense of security may lead to resistance. Similar reasoning applies for placing a station in an otherwise quiet neighbourhood because of the noise of sirens.

Besides some main questions as addressed in Table 3, there are mathematical models which help to locate stations. Jia et al. (2005) make a distinction based on the objective function of the location models and distinguishes between covering models, P-median models, and P-centre models. The different objectives of these models will be explained here, since these objectives largely determine the number and locations of stations.

Covering models are the most common facility location models where the objective is to provide 'coverage' to demand points. In these models a demand point is said to be covered by a site when the distance or travel time from the site to the demand point is smaller than some predefined time or distance limit. There are two main types of covering models: the location set covering problem (LSCP), introduced by Toregas et al. (1971), and the maximal covering location problem (MCLP), introduced by Church and ReVelle (1974). In the LSCP the objective was to minimize the number of ambulances/stations needed to cover all demand points, while the MLCP tries to make the best possible use of the limited available resources. Both models were deterministic location models and assumed that the nearest unit to a call for service is always available. (Swersey, 1994) These models can be used as a planning tool to decide on the minimal number of ambulances/stations, but since they ignore the availability of ambulances they are not conclusive. (Brotcorne, 2003) To incorporate for the unavailability of ambulances many extensions of these coverage models have been proposed, which include placing more than one vehicle at one location or locating facilities in a way that they overlap. Examples are BACOP1 (Backup Coverage Problem 1) and BACOP2 by Hogan and ReVelle (1986).
Besides deterministic models there are also probabilistic models which account for stochastic effects and consider the responsibilities and behaviour of individual units in a system. Most of these models assume that an ambulance is busy a certain percentage of the time and therefore incorporate a busy fraction. An example is the MEXCLP (maximum expected covering location problem) model from Daskin (1983), where it is the objective to maximize expected demand covered. In practice, variability in different time segments of the response time and the availability of ambulances affects the real coverage for calls. Activation input and mobilisation duration are often taken together as delay time; the time before the ambulance can travel to the scene. Models that do not account for the uncertainty in delay time, travel to scene time and availability components may overestimate the possible service level for a given number of ambulances and underestimate the number of ambulances needed to provide a specified service level. (Ingolfsson et al. 2008)
The first deterministic and probabilistic location models are summarized in Table 4. For a complete overview of all the different deterministic and probabilistic location models the reader is referred to Brotcorne et al. (2003).

In P-median models the objective is to minimize the average (total) distance between the demand points and the facilities. Stations are thus located in a way to minimize the average (total) distance between demand points and stations instead of covering a specific area. Early P-median models were deterministic models which can be used in a planning stage to determine the location of facilities. These models have been extended to incorporate uncertainties in availability and travel times. P-median models can also be used to dispatch ambulances during emergencies. For an example of this model see Mandell (1998).

P-centre models, in contrast to p-median models, have the objective to minimize the worst performance of the system. These models are also referred to as “minimax models” since they minimize the maximum distance between any demand point and its nearest facility.
For a further review on different models the reader is referred to ReVelle (1989), Swersey (1994), Marianov and ReVelle (1995), Brotcorne at al. (2003), and Jia et al. (2005).

Table 4 Early deterministic and probabilistic location models

Reference	Model	Objective	Coverage constraints	Constraints on location sites	Ambulances	Busy period
Toregas et al. (1971)	LCSM	Minimize the number of ambulances	Cover each demand point at least once	At most one ambulance per site	One type, Number unlimited	--
Church and ReVelle (1974)	MCLP	Maximize the demand covered		At most one ambulance per site	One type, Number given	--
Hogan and ReVelle (1986)	BACOP 1, BACOP 2	Maximize the demand covered twice, or a combination of the demand covered once or twice	Cover each demand point at least once	At most one ambulance per site	One type, Number given	--
Daskin (1983)	MEXCLP	Maximize the expected demand covered	None	None	One type. Upper bound given	Same for each ambulance. Given value

In summary, there are numerous potential locations for ambulance stations. Specific locations of stations largely depend on the objectives of the system and the available budget. Covering models are the most widespread location models used in emergency facility location problems. (Jia et al., 2005)

EMS resource schedule (2/4)

Besides where the stations should be located, there is an important question of which type of vehicle should be operational at which base at what times. There are a few aspects of an EMS system that need to be determined before such a specific resource schedule can be created. These are the following:

1. Type of EMS system (staffing); what level of care should personnel be able to provide? Should the focus be on bringing care to the patient, or bringing the patient to a hospital?
2. Type of deployment system; how do you handle different calls (urgent/non-urgent) and what type of resources are needed to handle these calls?
3. Type of vehicles; based on the type of deployment system there can be different type of resources fulfilling different roles in the EMS system.
4. Type of shifts; does labour legislation or financial costs make some shift options more (un)attractive?

When the aspects above are addressed it all boils down to determining the right quantity of resources by creating a good fit between demand for EMS and supply of EMS.

Aspects of EMS resource schedule

Type of EMS system (Staffing)

There are many different approaches to EMS delivery throughout the world. There are two paradigms that are most common. In the first, the ambulances are staffed by basic or paramedic level Emergency Medical Technicians (EMT). The EMTs initiate the treatment where after the patient is transported to the hospital as soon as possible. This is the predominant system in the United States, and is also called Anglo-American EMS system (AAS). In the second system, an Emergency Physician (EP) will arrive at the patient. In these systems it is the aim to provide more care on the scene. (Dib et al., 2005) These systems are also called Franco-German EMS systems (FGS). For a review of these two main types of EMS systems (Anglo-American vs. Franco-German EMS systems), the reader is referred to Wolfgang (2003). The Dutch system is a bit different from both these main EMS systems. In the Dutch EMS system, the ambulances are staffed with a registered nurse. These nurses have a higher level of education than EMTs, but lower than EPs. A detailed overview of different skillsets falls outside the scope of this thesis since it does not influence the response time. It does influence the quality of the provided care. However, quality is not a performance measurement in this logistic project. In summary most ambulances are staffed with two employees who at least have some kind of Basic Life Support training. In many EMS systems ambulances have one designated driver with BLS training and one paramedic, nurse or physician.

Type of deployment system

There are two principal types of ambulance deployment systems which are relevant (Stout et al., 2000):

1) The multi-purpose, sole provider all-advanced life support (all-ALS) ambulance system in which all ambulance-related services (emergent and non-emergent) for a city or region are provided by one fleet of ambulances, each of which is staffed with ALS providers and
2) The tiered ambulance system (tiered) in which there are different kind of ambulances and staff were some ambulance are staffed with ALS providers and some ambulances are staffed with basic life support (BLS) providers. There are three main types of tiered systems (Braun et al., 1990):
    A. ALS units respond to all calls. Once on scene, an ALS unit can turn a patient over to a BLS unit for transport.
    B. ALS units do not respond to all calls; BLS units may be sent to noncritical calls
    C. A non-transport ALS unit is dispatched with a transporting BLS unit. For ALS calls, ALS personnel join BLS personnel for transport.

Stout et al. (2000) provide a comparison of these two main types of deployment systems. The main advantages and disadvantages of both systems are displayed in Table 5.

Table 5 Overview advantages and disadvantages different deployment systems

The all-ALS system	The tiered-response system
Advantages - can significantly reduce response intervals while simultaneously provide operational efficiencies when managed with advanced system status management (SSM) techniques; - can be used to readily integrate and expand the scope of services for the ambulance provider service; - all-ALS ambulance systems can typically be funded at a lower level than typical tiered systems; - it has the potential to enhance disaster capability, since many ALS units can be deployed quickly.	Advantages: - in large urban centres, reduce response intervals to critical calls, primarily through the use of sophisticated dispatch triage protocols; - requires less ALS-skilled staff and thus decreased staffing and training costs; - can provide medical care advantages in terms of skills utilization for individual ALS providers as well as more concentrated focus for medical supervision.
Disadvantages: - an all-ALS ambulance system can also be more costly because you need more ALS-skilled staff; - might lead to skill degradation because ALS-skilled staff handles less emergency calls; and - ambulances might be busy taking care of less urgent calls which affects the availability for the most urgent calls.	Disadvantages: - a tiered system may not be justifiable in a suburban system with a low population density where there is a lack of resources or there is only one ambulance needed; - pooling effects may be less since BLS-ambulances cannot respond to high priority calls.

According to Stout et al. (2000):
"Both of these deployment systems can offer certain advantages depending on local emergency medical services (EMS) systems needs as well as the local philosophy of health care delivery. Applicability must therefore be considered in terms of local service demands and other factors that affect the EMS system, including catchment population, statutory and jurisdictional issues, available funding, accessibility of receiving facilities and medical quality concerns."

Type of vehicles

In tiered systems, there are multiple types of vehicles. Their specific use depends on the type of deployment system. Three main types of vehicles can be distinguished:

- ALS ambulances; advanced life support ambulances. These ambulances are usually staffed with higher skilled personnel than BLS ambulances and respond to urgent emergency calls.
- BLS ambulances; basic life support ambulances. These vehicles are usually staffed with paramedics. These vehicles are sent to non-critical calls where transport is required.
- Rapid responders; for example a motor, may consist of an ALS provider which can initiate the treatment and triage the level of additional response needed. They cannot transport a patient; the focus here is on getting a high-level provider at the scene quickly, rather than a transport vehicle. (Stout et al., 2000)

Besides these main types of vehicles, EMS systems can also make use of helicopters, boats or bicycles.

Type of shifts

EMS systems provide 24/7 services which require ambulance staff to work during the night, weekends and on holidays. Since demand is typically higher at daytime, not all vehicles should operate on a 24/7 basis. Therefore, vehicles can also be scheduled to operate only a part of the day. Different types of shifts common in Dutch practice are:

- active duty; staff is at the base or in the vehicle
- presence duty; staff sleeps in the base
- availability duty; staff is at home but available

Besides these three main types of shifts, the actual design of various schedules is constrained by physical number of units and labour legislation. Detailed models exist for generating schedules for specific employees. These detailed models fall outside the scope of this thesis. The interested reader is referred to Trudeau et al. (1989), Aubin (1992), Erdogan et al. (2010), and Li and Kozan (2009). Typical issues that should be addressed in creating shift schedules are:

- Length of the shifts
- Starting and ending times
- Meal breaks
- Smoothing of capacity; i.e. do not start and end all shifts at the same time. Abrupt changes in capacity increases the volatility between ambulance supply and demand.
- Labour legislation

Building a resource schedule

Besides the different type of vehicles, shifts and staff there are a few other important elements that should be addressed in order to create a good fit between the demand for EMS and the supply of ambulances. These are demand patterns and pooling effects between different vehicles. An ambulance can only be operational when it can be staffed with an ambulance team. Since personnel makes up a large part of the total costs of an EMS system, different shifts should be scheduled to fit demand without using more units than necessary. Therefore demand patterns should be analysed to match capacity to demand. There can also be some synergy effects between multiple vehicles when these vehicles have an overlapping area, these pooling effects are explained below. First the demand patterns are addressed.

<u>Demand patterns</u>

Often, there are some typical demand patterns which can be identified (Aubin, 1992):

- demand is higher in the winter;
- demand is lower in the summer;
- ordered transport in mainly on weekdays;
- urgent calls are random and occur mainly at daytime during working hours;
- Thursday, Friday and Saturday nights are more active than other nights, especially in the summer.

Although these demand patterns are typical, this does not mean that they occur in every region in the same way. Specific demand patterns are unique and should therefore be analysed per region.

It is often suitable to create a schedule with a period of one week since: 1) the number of emergency calls received behaves in a cyclic manner with a one-week period; 2) shifts are usually planned so that staffing is constant from week to week. (Erdogan et al., 2008)

Pooling effects

Besides demand patterns, the planner should understand pooling effects in matching capacity to demand. In areas with high demand there might be multiple vehicles needed to cover for the possibility that calls occur simultaneously. However, when two bases overlap in coverage, they can both serve a call in this overlapping area which shortens the queuing ratio in that area. Besides this pooling effect between stations, there are also pooling effects in a single station. Holding the utilization ratio constant, the bases with more ambulances – and serving a proportionally larger demand – perform better in terms of average queuing ratio than bases with fewer ambulances. (Restrepo, 2008)

Dispatch policy (3/4)

The ambulance dispatch problem can be divided into two main issues: the method of call queuing and the way of assigning an ambulance to answer an emergency call in the queue. (Lim et. al, 2011) The different issues with their main methods are explained below and summarized in Table 6.

Method of call queuing

There are two main methods of call queuing; the dispatcher either classifies the call into a specific category based on the urgency of the call or the operator does not make this classification. When calls obtain a priority this can be done based on criteria based dispatch (CBD) or advanced medical priority dispatch (AMDP). In the former predetermined guidelines help the dispatcher to reach a priority decision while in the latter scripted questions and protocols are followed. (Lim et. al, 2011) The type of priority dispatching may impact the amount of calls and/or mix.

Method of assigning an ambulance

There are two main methods for assigning an ambulance to a call: closest dispatch or non-closest dispatch. In theory, it might not always be the best choice to dispatch the closest unit to the scene. (Carter et al., 1972) When there is an area which is partly covered by two stations with both one ambulance, it might be better for the overall performance to send the unit from the area whit the lower call frequency, although it might be a bit further away (but still within limits). This decision lowers the probability that the next call will be left uncovered, since the unit with the higher call frequency is still available. Another example is the following. Assume there are three ambulance stations: A, B, and C. In this case, sending unit C to take A's call when A is already busy, instead of sending the closer unit B when the call frequency is higher for B's area can improve the overall performance. (Repede and Bernardo, 1994) These non-closest dispatches procedures combine coverage with probability or preparedness (Andersson and Vaerbrand, 2007) to determine the proper ambulance for call assignment. Instead of reducing the response time for each call, these methods aim to improve the overall response time performance. Although this might sound logic in theory, there seems to be no real alternative to 'dispatch the closest available ambulance' that would be acceptable in practice according to Ingolfsson et al. (2008). There may also be legal complications for not dispatching the closest available unit.

Besides the distinction between closest and non-closest dispatch there are also a number of add-on dispatch methods which can further improve the dispatching policies. The most important example is the reassignment of an ambulance to a more urgent call when this ambulance was on his way to a lower priority call. This reroute-enabled dispatch improves the response times of the most urgent calls while it increases the waiting time for less urgent calls.

Table 6 Dispatching policies: core methods and description

		Core methods	Description
Dispatching policies	Method of call queuing	- Priority dispatching	In priority dispatching a priority is assigned to a call. A distinction can be made between criteria-based dispatch (CBD) and advanced medical priority dispatch (AMPD). In the former predetermined guidelines help the dispatcher to reach a priority decision while in the latter scripted questions and protocols are followed
		- First-in-first-out dispatching	In first-in-first-out dispatching there is no distinction between the priority of a call and the calls are served based on the sequence of the calls. This method can only be applied in uniform systems.
	Method of assigning an ambulance	- Closest dispatch	The most common decision for assigning an ambulance is to send the closest available unit since it is the objective to reach the patient as soon as possible. This can be either in a tiered or a uniform system
		- Non-closest dispatch	Sending a unit to a call with the aim to reduce the overall response times

Relocation strategy (4/4)

The relocation strategy comprises the decision of relocating vehicles when an area is left uncovered. These relocation policies can significantly contribute to improving the response times of EMS systems. (Lim et al., 2011)
A distinction can be made between three types of relocation strategies:

- no relocation strategy
- cover specific places, and
- dynamic relocation

When there is no relocation strategy, all vehicles return to their bases after a deployment. The second type of relocation strategy makes sure some places are covered, based on predefined protocols or judgement of the dispatcher.
For dynamic relocation a redeployment plan is calculated in real-time based on available information at that time. In this way an ambulance deployment strategy can be recalculated at any moment in time. (Brotcorne et al., 2003) Models that address these policies are referred to as dynamic models. Dynamic models update ambulance positions throughout the day and can therefore handle the fluctuating demand over time.
In order to create good solutions these dynamic models should be based on exact demand patterns for different areas on a highly detailed level of aggregation. When the level of detail is decreased this can overestimate the solution dramatically. See Francis et al. (2009) for a detailed analysis for this ‘optimality error’. Time-dependent travel times should also be considered since these travel times can change significantly throughout the day. (Schmid and Dourner, 2010)

From Gendreau et al. (2001)
There are a few practical constraints which need to be addressed in a dynamic relocation model:

- a limited number of ambulances can be positioned at each site;
- only a limited number of ambulances can be moved when a redeployment occurs;
- vehicles moved in successive redeployments cannot be always the same
- repeated round trips between two location sites must be avoided;
- long trips between initial and final location sites must be avoided;
- an assignment to a call should be avoided near the end of a working shift; and
- ambulances can only be relocated to bases that the ambulance can reach within a drive time limit.

Dynamic models have received more attention in the last couple of years because of technological progress. Geographic positioning system (GPS) makes it possible to trace vehicles in real-time and geographic information system (GIS) makes it possible to report those vehicles on a computerized map. These systems together with improved computing power make it possible to solve problems from realistic dimensions.

3.3 Summary

This chapter answered the first research question: “In what way can the performance of EMS systems be measured and what are the key logistic design parameters of EMS systems?”
It was found that response times are a widely accepted performance indicator. However, response times are a surrogate performance indicator for the real effectiveness of an EMS system.
Four key logistic parameters were identified. Table 7 provides an overview of the different logistic design parameters of an EMS system with their possible values.

Table 7 Overview logistic design parameter of EMS systems and their values

Level	Parameter	Values
Strategic	1. Number and location of stations	It is possible to create many different bases on different locations
	1. EMS resource schedule	It is possible to expand the fleet with as many units as possible and schedule shifts all over the day. Schedule is based on: <u>Staffing</u> - Paramedics; low-skilled - Registered nurses; medium-skilled - Physicians; high-skilled <u>Type of deployment system</u> - Tiered system; separation between different type of vehicles o Type A: ALS respond to all, BLS transport o Type B: ALS urgent, BLS non-urgent o Type C: non-transport ALS with transport BLS - All-ALS system; one type of vehicle handles all calls. <u>Type of vehicles</u> - ALS vehicles; advance life support for urgent emergency calls - BLS vehicles; basic life support for transport non-critical calls - Rapid responders; provides high level care rather than transport <u>Type of shifts</u> - Active duty; staff is in the vehicle or at the base - Presence duty; staff sleeps in the base - Availability duty; staff is at home but available
Tactical	2. Dispatching policy	<u>Method of call queuing</u> 1) Priority dispatching a) Criteria based dispatching (CBD); based on predetermined guidelines b) Advanced medical priority dispatch (AMPD); based on scripted questions and protocols 2) First-in-first-out dispatching <u>Method of assigning an ambulance</u> - Closest dispatch; closest available ambulance is assigned to the call - Non-closest dispatch; ambulance are dispatched with the aim to reduce overall response times
	3. Relocation strategy	- No relocation strategy; all vehicles return to their home bases - Cover specific places; some places should be covered - Dynamic relocation; redeployment plan is calculated in real-time based on available information at that time

4. CURRENT SYSTEM DESIGN

The Northern Province Drenthe of the Netherlands has a population of 492.000. With a density of 186/km², it is one of the lowest density regions of the Netherlands. Drenthe has one Regionale Ambulance Voorziening (RAV), in charge of all EMS affairs. How this EMS system is organised is the subject of this chapter. This chapter forms the first step of the research step plan defined in chapter 2 and answers the second research question: "How can the current EMS system be characterised?"

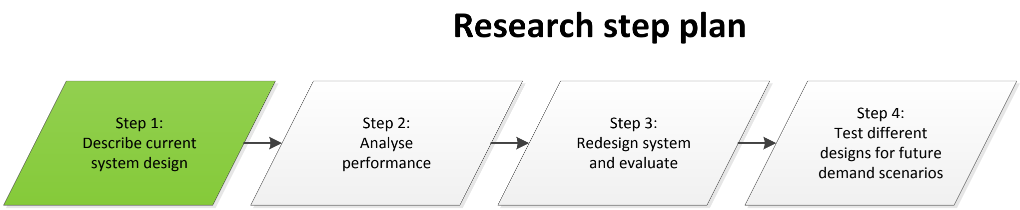


Figure 6 Research step plan: step 1

Figure 7 provides the aspects from the conceptual model that are addressed in this chapter.

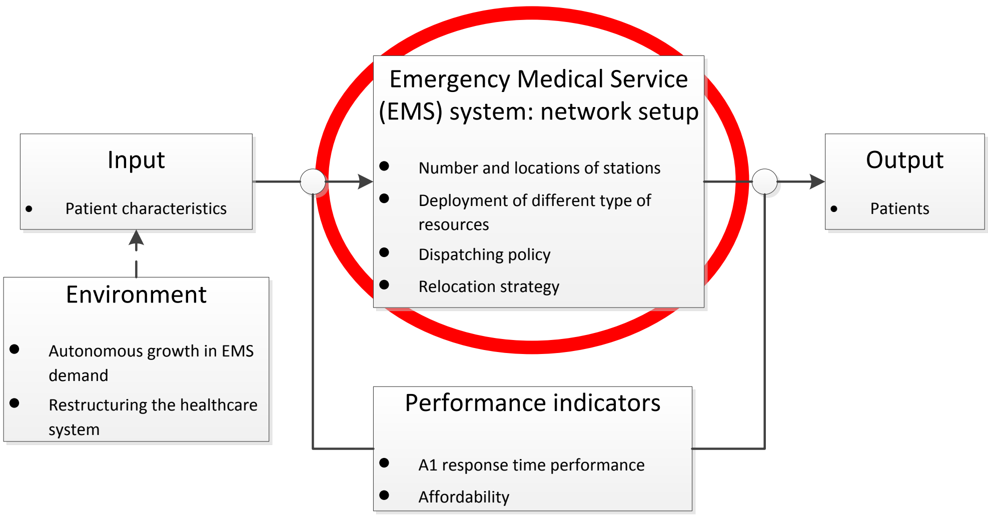
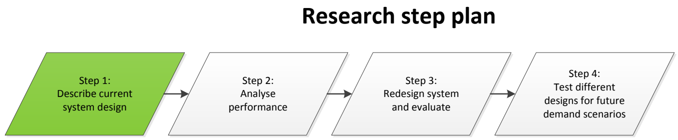


Figure 7 Conceptual model: aspects addressed in chapter 5

Every EMS deployment, whether urgent or not urgent, starts with a demand for EMS by dialling the control centre. The control centre is addressed in section 4.1. The specific process and targets of the most important A1 calls is addressed in section 4.2. After an assignment by the control centre, an ambulance team proceeds to the patient. If necessary, the patient is transported to a hospital or brought home in case of an ordered transport. The ambulance team with their resources, staffing and the resource schedule is addressed in section 4.3.

Figure 8 provides a general overview of the EMS system.



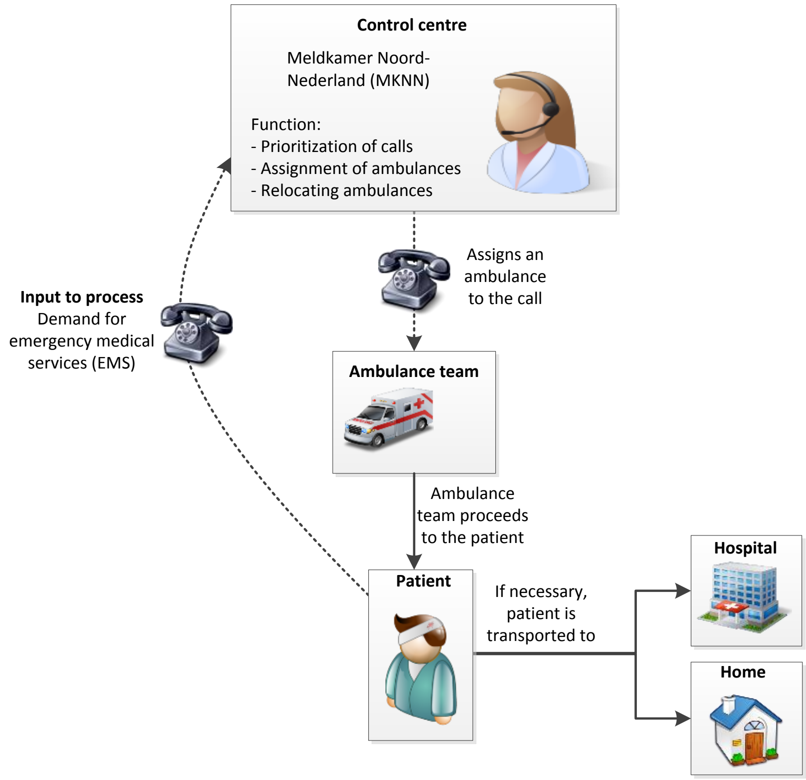


Figure 8 General overview of the EMS system

4.1 The control centre

There is one control centre Meldkamer Noord-Nederland (MKNN) for the three Northern Provinces Friesland, Drenthe and Groningen. This control centre can be accessed by dialling 1-1-2 which also connects emergency calls to the fire and police departments. When an ambulance is requested, the call is reconnected to a nurse.
The control centre has three major functions:

- Assign a priority to the call (section 4.1.1)
- Assign an ambulance to the call (section 4.1.2)
- Relocate ambulance to obtain coverage in the area (section 4.1.3)

Besides these three major functions the nurse can also give medical advice.
These three major functions are addressed below.

4.1.1 Prioritization

In the Netherlands the EMS system is a nurse-triaged system which makes use of criteria based dispatching. This means that there are predetermined guidelines which help the dispatcher to reach a priority decision. Emergency calls are classified as either A1 in case of a (potential) life-threatening situation, A2 in case the situation is serious but not immediately life threatening or B when an ambulance is needed to transport a patient when the situation is neither serious nor life-threatening. Based on this prioritization, UMCG ambulancezorg offers the following services:

Table 8 Services UMCG Ambulancezorg

A1 deployment: an emergency deployment with A1 priority assigned by the dispatcher in the control centre in case of direct threat of the vital functions of the patient or when this threat can only be excluded after examination by the ambulance team at the scene. The ambulance team should be as soon as possible at the scene and may make use of lights and siren. 95% of the calls should be within a 15 minutes response time

A2 deployment: an emergency deployment with A2 priority assigned by the dispatcher in the control centre in response to a request for help when there is no immediate life danger, but there can be (serious) health damage and the ambulance team should be as soon as possible at the scene. 95% of the calls should be within a 30 minutes response time.

B deployment: a deployment with B priority assigned by the operator in the operating room in response to a request for help without A1 or A2 priority, wherefore a time or time interval is agreed upon to pick up or bring a patient. UMCG ambulancezorg also differentiates between B1 and B2 priority deployments, for the former there is some health risk involved and an ALS ambulance with a registered nurse is required.

Not every call receives a priority; the nurse can also provide medical advice and determine that the patient will not receive medical care from an ambulance.
The division between the number of different deployments for the years 2009, 2010 and 2011 for the region Drenthe is presented in Table 9. The table includes voorwaardescheppende ritten; indicated with a 'V' (see section 4.1.3 for an explanation).

Table 9 Number of deployments for the region Drenthe (Dundas)

	2009	2010	2011
A1	13.247	13.633	9.877
A2	11.138	11.713	16.079
A1 + A2	24.385	25.346	25.956
B1	1.536	1.490	1.929
B2	6.776	6.734	7.220
V	591	59	76
Total	**33.288**	**33.629**	**35.181**

In 2011, the number of A1-priority calls has dropped while the number of A2-priority calls has increased simultaneously. This is due to a change in the priority dispatching in the control centre.

4.1.2 Assignment of ambulances

The dispatcher in the control centre assigns a vehicle to a call based on written protocols. These protocols are made on a higher level and are the responsibility of the board of directors. The daily execution of these protocols is the responsibility of the MKNN. The main A1 protocol can be described as follows:

In case of an A1-priority call: closest with re-route enabled dispatch. The closest available unit (ALS or rapid responder) is assigned to the call.

- In case this unit is a rapid responder and transport might be required, then the closest available ALS-ambulance is also sent.

- Re-route enabled: the dispatcher can reassign an ALS ambulance on the road which was on his way to a lower priority call when this ambulance is the closest unit.
- For reanimations send two units (ALS + ALS or solo)

4.1.3 Relocation strategy

In order to provide good coverage the dispatcher works according to the national protocol: Dynamisch Ambulance Management (DAM) and may dispatch available ambulances from neighbour regions. Dispatchers have a graphical map which shows the actual location of different ambulances from their own and other regions. The general rule is that the HEMA places (Hoogeveen, Emmen, Meppel, Assen) are covered (covered but not necessarily an ambulance on location). The outside areas are covered as good as possible based on spreading available units. The dispatcher may relocate units on strategic locations when he believes this is necessary. These are so-called: ‘voorwaardescheppende ritten’ (vws). The dispatcher remains responsible for the spreading and availability of units. In 2010, there were only 59 voorwaardescheppende ritten in Drenthe.

4.2 A1-priority calls: targets and process description

Section 4.1.1 differentiated between different call classes based on the priority of the call. This section aims to provide a better understanding of the targets (section 4.2.1) and the main process of the most important call class; A1-priority calls (section 4.2.2).

4.2.1 A1 targets

A1-priority calls receive the highest priority from the call classes. As shortly addressed in section 2.3.5 the response time can be divided into three time segments for ambulances idle at its base:

- ‘Activation Input’ (Received to Dispatch),
- ´Mobilisation Duration´ (Dispatch to Mobilised), and
- ‘Travel to Scene’ (Mobilised to Arrival)

Receiving a call and dispatching takes about two minutes, mobilisation about one minute at daytime and two minutes at night. For ambulances already on the road there is no ‘Mobilization Duration’. This leaves 11, 12 or 13 minutes for the vehicle to travel to the scene depending on whether the ambulance is already on the road and whether it is day or night. In most occasions the ambulance departs from its base at daytime. This leaves 12 (=15-2-1) minutes to drive towards the scene in order to achieve the 15 minutes response time target.

The total reach hospital time is the time between call received time and the arrival at the ED. Table 10 provides an overview of these time segments for the A1-priority calls.

The target of interest in this research is the 15 minutes response time and in particular the travel to scene time segment of this response time. These are displayed bold in Table 10.

Table 10 Different time segments and their targets for A1-priority calls

Time segment	Preferred timespan	Target
'Activation Input' (Received to Dispatch);	ASAP	< 2 minutes
'Mobilisation Duration' (Dispatch to Mobilised)	ASAP	< 1 minute at daytime < 2 minutes at night
'Travel to Scene' (Mobilised to Arrival)	ASAP	< 11 minutes **< 12 minutes** < 13 minutes
'All Vehicle Response (Clock Start to Arrival	ASAP	**< 15 minutes for > 95%**
'At Scene Duration' (Departure time – First vehicle arrival time)	Patient specific	No target Theoretical duration: 5 minutes
Reach Hospital Time	Patient specific	< 45 minutes

4.2.2 A1 process description

Figure 9 displays the different process steps and corresponding time intervals for an ALS ambulance with an A1 call. The different time intervals are displayed on the left.

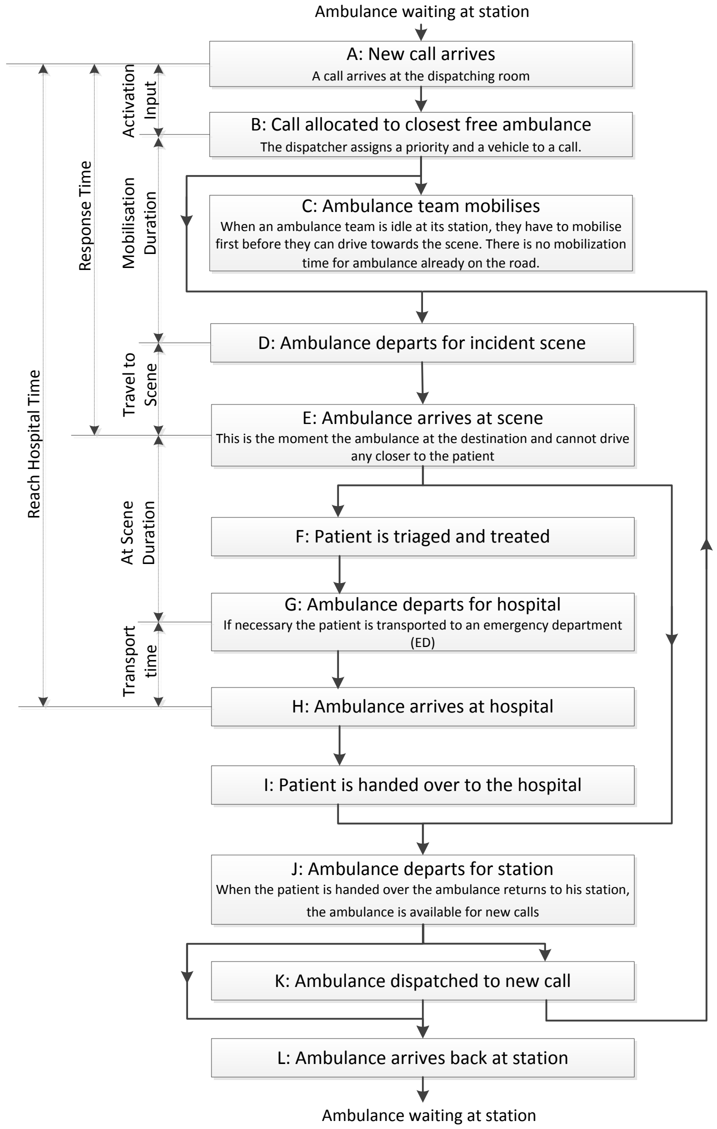


Figure 9 Business process for A1-priority calls (Adapted from Henderson and Mason [2004])

4.3 Ambulance team: resources

The demand for different EMS in Drenthe is served by ambulances from UMCG ambulancezorg. The available resources (stations and ambulances) in this operational process are addressed in sections 4.3.1 and 4.3.2. The staffing and resource schedule are addressed in sections 4.3.3 and 4.3.4.

4.3.1 Ambulance stations

The locations of bases are calculated based on the (deterministic) national coverage and availability framework 2008 from RIVM. This framework determined that the region Drenthe should suffice with 11 different stations. These 11 stations should be sufficient to cover at least 97% of the population within a drive time of 12 minutes according to the framework. UMCG ambulancezorg receives a budget for these 11 stations from the Health Insurance Company. UMCG ambulancezorg has created two additional stations besides these 11 stations. These stations are not funded by the Health Insurance Company. In total there are 13 different stations. Moving or creating a station is only allowed in consultation with the Health Insurance Company and government. Figure 10 shows a map with the current locations of the 13 stations.

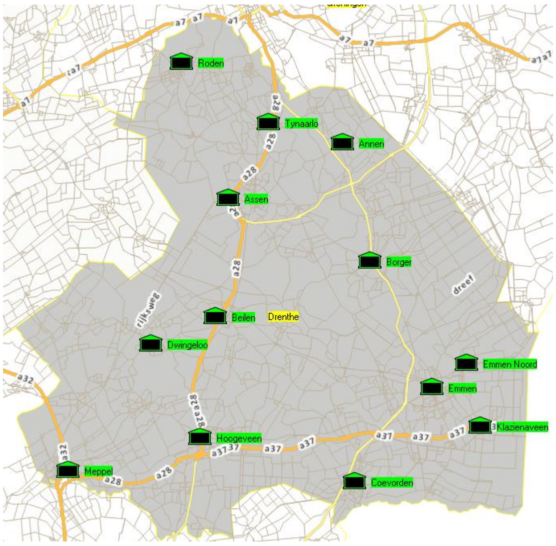


Figure 10 Location of stations in Drenthe 2012

4.3.2 Ambulances

In Drenthe there is a tiered system with:

- ALS ambulances. These vehicles are used for A1-, A2 and B1-priority calls were medical treatment is required. ALS ambulances can also respond to B2 calls when BLS ambulances are not available.
- BLS vehicles. These vehicles are used for B2-deployments. These are planned non-emergency calls were no treatment is required.
- Rapid responders. Rapid responders are used for A1 and A2 deployments. These vehicles cannot transport a patient. There are two type of rapid responders or solo’s in Drenthe:
    - solo-ambulances (car)
    - motor

The number of necessary ALS vehicles is calculated, like the locations of stations, based on the (deterministic) national coverage and availability framework from 2008. This framework determined that the region Drenthe should suffice with 13 to 19 ALS ambulances depending on the time and day of the week. The current resource schedule can be found in section 4.3.4.

4.3.3 Staffing

All ALS and BLS ambulances are staffed with two employees. BLS personnel receive a basic level of training. For ALS ambulances there is one nurse and one dedicated driver. The medical training of the driver is SOSA (Stichting Opleidingen Scholingen Ambulancehulpverleners) certified with the focus on driving skills and medical assisting procedures. The nurses have completed the full training required for a registered nurse. Besides this training, they have received additional training in anaesthesia, intensive care, cardiac care, or experience at an emergency department. In the Netherlands nurses may follow the protocols and independently administer drugs without consultation of a physician. A Medical Manager, which is a licenced physician, conducts medical oversight for protocol compliance. When the patient's condition exceeds the nurse protocols, the nurse can either call his Medical Manager for additional instructions, or request the response of a mobile medical team (MMT). These MMTs are staffed with a medical specialist, a specialised nurse and a pilot that flies the helicopter. When weather restricts flight operations, a MMT can also use a special van. The nearest helicopter is stationed in Groningen.

4.3.4 Resource schedule

Type of shifts

The total shift schedule is displayed in Figure 11. There are 13 shifts during the night. These 13 shifts are based on the calculation from the national coverage and availability framework 2008. All these night shifts are part of a 24-hour shift. 24-hour shifts are preferred by the direction since they are cheaper than a 3x8-hour active duty equivalent. The starting time of most shifts is 08.00. This is historically grown since hospitals normally start at 08.30. The end-time of most day shifts is 17.00. This is also the end-time of normal working days for other professions. In total there are:

- Presence duty

13x 24-hour shifts ALS (sleeping at night)

- Active duty:

5x 9-hour dayshifts ALS (weekdays)
4x 9-hour dayshifts BLS (weekdays)
1x 9-hour dayshift solo-ambulance (weekdays)
1x 8-hour dayshift solo-ambulance (weekdays)
1x 9-hour dayshift motor (all days)

1x 9-hour dayshift ALS (weekend)

The 24-hour shifts are constructed as follows: the shifts are from 08.00 to 08.00 the next day. The employees are allowed to sleep between 23.00 and 08.00 the next day.

Complete resource schedule Drenthe

There is chosen to create a schedule with a period of one week.
Note that: 24= 24hour shift; D= ALS day; DB= BLS day

Shifts Drenthe in 2012

Ambulances	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Which days
Annen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Assen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Assen_02_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Assen_03_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Assen_04_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Assen_05_solo									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Beilen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Borger_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Coevorden_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Dwingelo_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Emmen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Emmen_02_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Emmen_03_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Emmen_04_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Emmen_05_Solo															■	■	■	■	■	■	■	■			Mon.-Fri.
EmmenNoord_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Hoogeveen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Hoogeveen_02_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Hoogeveen_03_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Hoogeveen_04_D9										■	■	■	■	■	■	■	■	■							Sat.-Sun.
Klazienaveen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Meppel_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Meppel_01_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Roden_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Tynaarlo_01_motor									■	■	■	■	■	■	■	■	■								all
Tynaarlo_02_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.

Figure 11 Resource schedule Drenthe 2012

4.4 Summary

This chapter answered the second research question: "How can the current EMS system be characterised?"

In the previous chapter a distinction was made between four logistic design parameters. Based on the description of the current system Table 11 can be constructed with the four design parameters and their current interpretation.

Table 11 Design parameters and their current interpretation

Level	Parameter	Values	Current interpretation
Strategic/ resources	1. Number and location of stations	It is possible to create many different bases on different locations	13 different stations See Appendix D for specific locations
	2. EMS resource schedule	It is possible to expand the fleet with as many units as possible and schedule shifts all over the day. Schedule depends on: <u>Staffing</u> - Paramedics - Registered nurses - Physicians <u>Type of deployment system</u> - Tiered system - All-ALS system <u>Type of vehicles</u> - ALS vehicles - BLS vehicles - Rapid responders <u>Type of shifts:</u> - Active duty - Presence duty - Availability duty	See Appendix E for specific schedule <u>Staffing</u> Registered nurses <u>Type of deployment system</u> Tiered system, type B: ALS urgent, BLS non-urgent. With rapid responders. <u>Type of vehicles</u> - 25 ALS and 2 back-up ambulances - 4 BLS ambulances - Rapid responder: 1 motor 5 solo's (car) <u>Type of shifts</u> - Presence duty 13x 24-hour shifts. ALS (sleeping at night) - Active duty: 6x 9-hour dayshifts ALS (weekdays) 1x 9-hour dayshift ALS (weekend) 4x 9-hour dayshifts BLS (weekdays) 1x 9-hour dayshift Solo (weekdays) 1x 8-hour dayshift Solo (weekdays) 1x 9-hour dayshift Motor (all days)
Tactical / policies	3. Dispatching policy	<u>Method of call queuing</u> 3) Priority dispatching 4) First-in-first-out dispatching <u>Method of assigning an ambulance</u> - Closest dispatch - Non-closest dispatch	<u>Method of call queuing</u> Priority dispatching (CBD) <u>Method of assigning an ambulance</u> Closest with re-route enabled dispatch
	4. Relocation strategy	- No relocation strategy - Cover specific places - Dynamic relocation	Cover specific places (HEMA)

5. PERFORMANCE ANALYSIS

Before a system can be redesigned, the current performance should be analysed. In this chapter the second step from the research step plan is addressed and the third research question is answered: "What is the performance of the current EMS system and how can this performance be explained?"

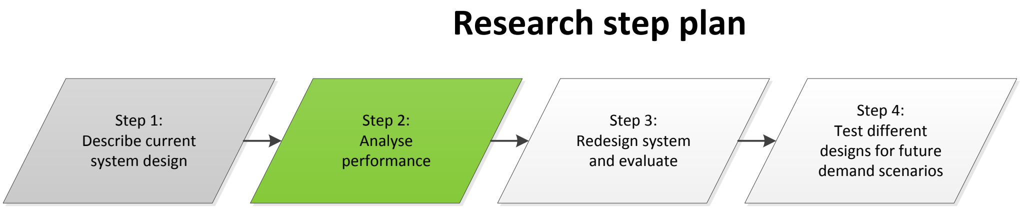


Figure 12 Research step plan: step 2

Figure 13 shows the aspects from the conceptual model that are addressed in this chapter.

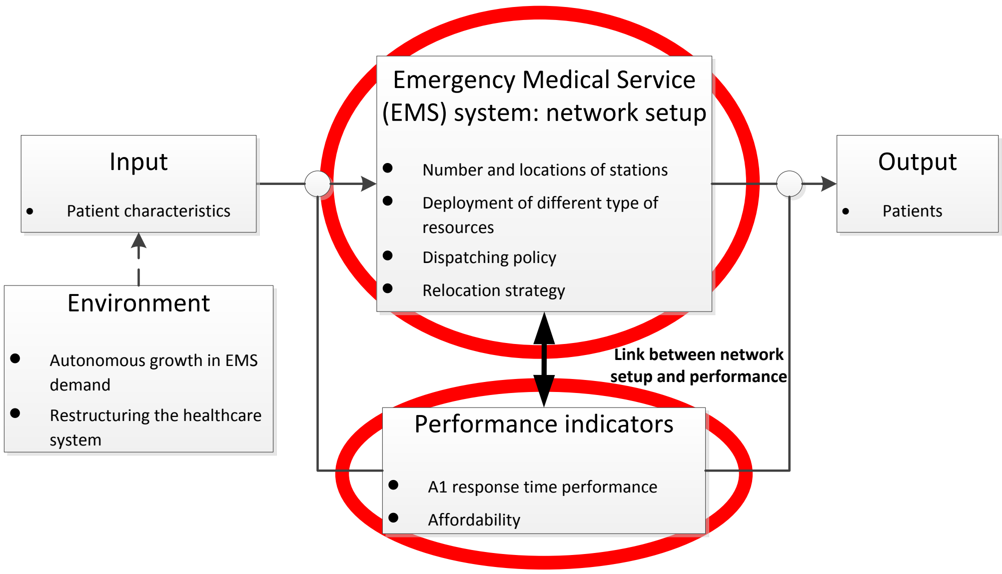


Figure 13 Conceptual model: aspects addressed in chapter 5

First the operational costs of the EMS system are calculated and decomposed. (Section 5.1) In section 5.2 demand for EMS and the A1 response performance is described and analysed. The major findings from section 5.2 are further analysed in section 5.3 to identify possible causes that contribute to a lower A1 response performance. This is the link between the network setup and the response performance as can be observed in Figure 13. These potential causes for a lower A1 response performance are listed and quantified were possible in section 5.4.

5.1 Costs of resources

First the operational costs of the EMS system are analysed. Acquiring insight into the operational costs components is relevant for redesigning the system since it is the objective to achieve a specified target at minimum costs. A pie chart of the different costs (stations, vehicles and staff) is presented in Figure 14. The cost calculation used to construct Figure 14 is presented in Table 12.

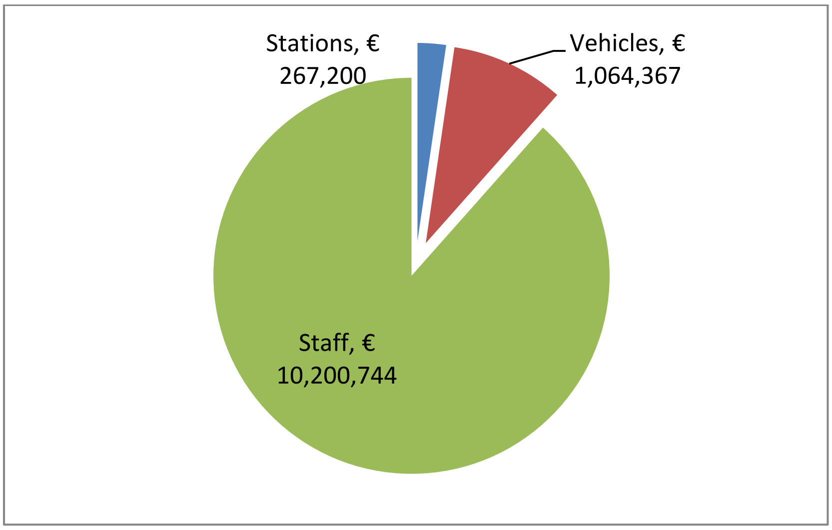


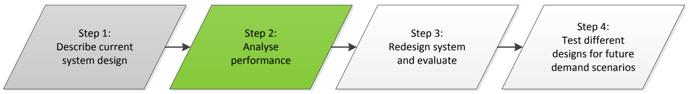
Figure 14 Cost overview UMCG ambulancezorg Drenthe 2012

From Figure 14 it is clear that personnel costs make up the largest part of the total yearly operational costs. Additional resources with additional staff are therefore not preferred. Table 12 presents the total estimated yearly operational costs for UMCG ambulancezorg in Drenthe for 2012. Costs are calculated as follows:

- buildings are depreciated over 50 years
- vehicles are depreciated over 5 years
- costs of shifts is based on actual salaries of drivers and nurses

Table 12 Cost overview UMCG ambulancezorg Drenthe 2012

Number			Costs per year	Total currently (2012)		
	Stations					
9	1 car post		€ 16,200	€ 145,800		
1	2 car post		€ 26,600	€ 26,600		
3	3 car post		€ 31,600	€ 94,800	+	
					€ 267,200	
	Vehicles					
18	ALS-Ambulance	Depreciation	€ 26,000	€ 468,000		
990000	Kilometres	Insurance	€ 1,000	€ 18,000		
		Fuel per KM	€ 0.20	€ 198,000		
		Maintenance per KM	€ 0.14	€ 138,600		
4	BLS-Ambulance	Depreciation	€ 20,000	€ 80,000		
260000	Kilometres	Insurance	€ 1,000	€ 4,000		
		Fuel per KM	€ 0.18	€ 45,500		
		Maintenance per KM	€ 0.12	€ 31,200		
2	Solo-ambulance	Depreciation	€ 11,800	€ 23,600		
100000	Kilometres	Insurance	€ 600	€ 1,200		
		Fuel per KM	€ 0.12	€ 11,667		
		Maintenance per KM	€ 0.08	€ 8,000		
1	Motor-ambulance	Depreciation	€ 10,000	€ 10,000		
80000	Kilometres	Insurance	€ 600	€ 600		
		Fuel per KM	€ 0.18	€ 14,000		
		Maintenance per KM	€ 0.15	€ 12,000	+	
					€ 1,064,367	
	Staff					
8	9 hours regular (mon-fri)		€ 172,187	€ 1,377,492		
1	9 hours regular (mon-sun)		€ 268,025	€ 268,025		
13	24 hours presence		€ 631,757	€ 8,212,844		
2	solo 9 hours regular (mon-fri)		€ 96,638	€ 193,277		
1	solo 9 hours regular (mon-sun)		€ 149,106	€ 149,106	+	
					€ 10,200,744	+
	Total costs				**€ 11,531,710**	



5.2 A1 response performance

This section analyses the A1 response performance in Drenthe. The A1 response performance was defined in chapter 2 as:

$$A1\ response\ performance = \frac{Number\ of\ A1\ calls\ within\ 15\ minutes\ response\ time}{Total\ number\ of\ A1\ calls} * 100\% \quad \text{(Eq. 2.1)}$$

Table 13 presents the total A1 response performance and average time intervals for the last couple of years for Drenthe (D) and the Netherlands (NL).

Table 13 Response performance A1 Drenthe (AZN, 2011)

	2011		2010		2009	
	D	NL	D	NL	D	NL
Activation Input	1:27 min	1:52 min	1:27 min	1:51 min	1:24 min	1:52 min
Mobilization Duration	0:46 min	1:02 min	0:44 min	1:02 min	0:43 min	1:09 min
Travel to Scene	6:48 min	6:36 min	6:53 min	6:45 min	6:44 min	6:42 min
Vehicle Response	9:05 min	9:32 min	9:08 min	9:40 min	8:54 min	9:44 min
< 15 minutes	93.7 %	93.3%	91.8 %	92.3%	93.4 %	92.0%

From Table 13 it can be observed that Drenthe is actually doing quite well on the different time segments of the response time compared to the Dutch average. Only the average travel to scene time is above the Dutch average. The A1 response performance is still below the 95% target.
In order to analyse the response performance, it is appropriate to look at all three units of equation 2.1. It is especially interesting to look at the complement of the numerator, i.e. the number of A1 calls over the 15 minutes response time. The following sections aim to analyse demand for EMS, the response performance and number of A1 calls over 15 minutes by:

- Location (section 5.2.1)
- Time (section 5.2.2)
- Location and time (section 5.2.3)

By making this segregation, time segments or areas that perform worse in terms of A1 response performance can be identified. Section 5.2.4 summarizes the main findings from sections 5.2.1-5.2.3. The main findings are further analysed in section 5.3 to link the performance to the logistic design parameters.

5.2.1 Demand and performance by location

The locational demand and performance overview is provided per municipality and for a grid size of 100x100. These two different divisions of the region are chosen since:

- The areas of the municipalities are pretty similar of the working areas of the bases.
- A grid-size of 100x100 (approximately 5 by 4 kilometres) provides more detail compared to municipalities.

Demand per location

The location of every call is registered, this allows for analysing the demand by location. Figure 15 shows the location and total demand for different EMS for the region Drenthe. The location of the call is indicated by a coloured box. Each call class (A1, A2, B1, and B2) is indicated by different colour. A distinction is made between ALS demand (A1, A2, B1) and BLS demand (B2).

a) A1,A2,B1 demand (Municipality) b) B2 demand (Municipality)

c) A1,A2,B1 demand (Grid 100x100) d) B2 demand (Grid 100x100)

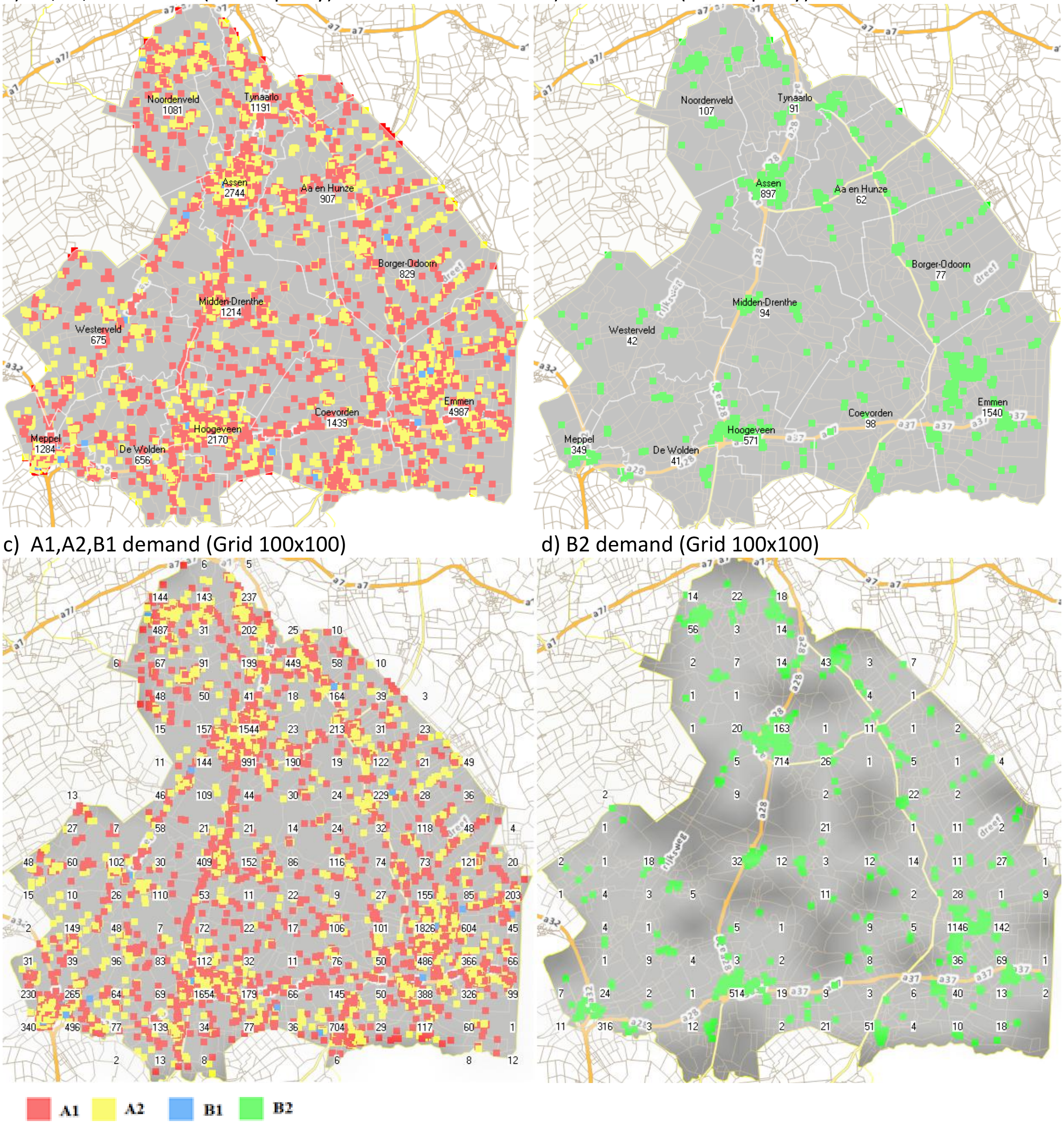
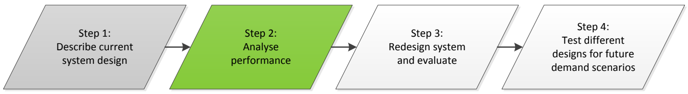


Figure 15 a-d) Location and number of calls Drenthe (Data: UMCG ambulancezorg, 01-01-2010 – 19-10-2010)

In the figure it can be observed that demand is typically higher in denser populated areas. Especially in the HEMA (Hoogeveen, Emmen, Meppel, and Assen) places.
B2 demand is the highest in Emmen, followed by Assen and Hoogeveen.

Performance by location

Figure 16 shows the A1 response performance per grid (100x100) and per municipality. The total number of A1 calls that contributed to the A1 response performance for each area is also displayed. The colour of the background provides an indication of the achieved A1 response performance. An A1 response performance of above 95% is green, below 85% is red, everything in between changes from green to red.



a) A1 response performance (Grid 100x100) b) A1 response performance (Municipality)

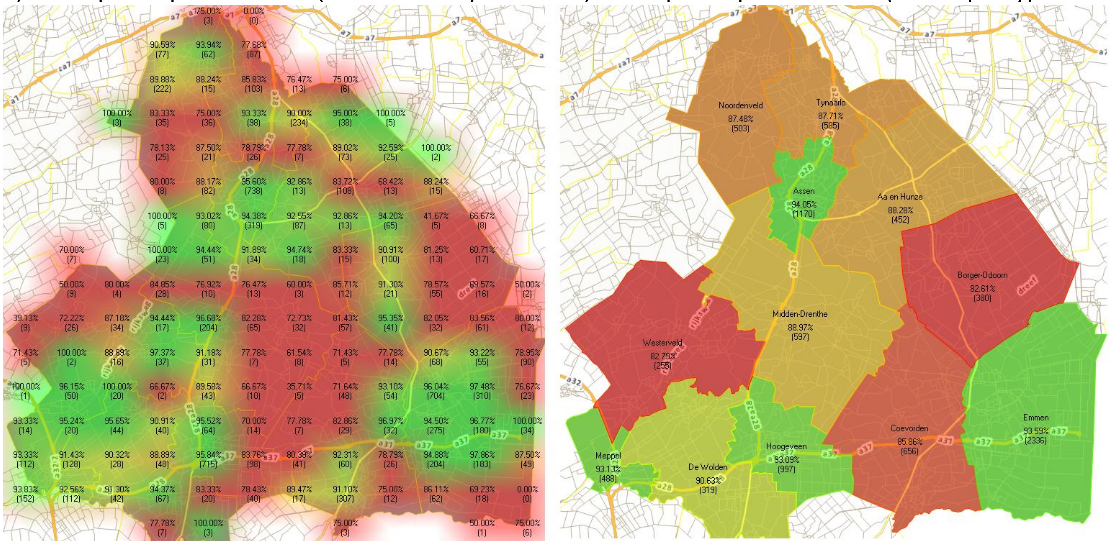


Figure 16 a-b) Percentage of A1 calls that had a response time of less than 15 minutes (Data: UMCG ambulancezorg, 01-01-2010 – 19-10-2010)

As can be observed from Figure 16a, the performance is quite high in urban areas and around the bases, especially in Emmen, Assen, Hoogeveen and Meppel. The performance is significant lower in more rural areas. The centre of Drenthe is coloured red in Figure 16a; this means that the A1 response performance is very low here. However, there are not many calls in rural areas. Therefore, not achieving the target for these calls in rural areas has less impact on the total response performance in Drenthe.

Table 14 provides an overview of the total A1 calls, A1 response performance, number of A1 calls with a response time over 15 minutes, and the contribution to the total number of A1 calls with a response time over 15 minutes per municipality for the years 2010 and 2011.

Table 14 Number of A1 calls > Norm per municipality (Dundas, 2010-2011)

	2010				2011			
	Number of A1 deploy-ments	Perc. <= Norm	Number > Norm	Perc. of total number > Norm	Number of A1 deploy-ments	Perc. <= Norm	Number > Norm	Perc. of total number > Norm
AA EN HUNZE	675	89.80%	69	6.0%	465	91.00%	42	5.7%
ASSEN	1,755	96.10%	69	6.0%	1,392	95.10%	68	9.2%
BORGER-ODOORN	636	82.20%	113	9.8%	424	89.20%	46	6.2%
COEVORDEN	1,060	85.70%	152	13.2%	757	87.30%	96	13.0%
DE WOLDEN	478	91.00%	43	3.7%	350	90.00%	35	4.7%
EMMEN	3,475	94.20%	200	17.4%	2,516	95.60%	110	14.9%
HOOGEVEEN	1,511	93.90%	92	8.0%	1,043	91.90%	84	11.4%
MEPPEL	688	93.80%	43	3.7%	532	91.00%	48	6.5%
MIDDEN-DRENTHE	937	88.60%	107	9.3%	602	90.40%	58	7.8%
NOORDENVELD	729	87.00%	95	8.3%	494	89.50%	52	7.0%
TYNAARLO	947	88.40%	110	9.6%	574	91.50%	49	6.6%
WESTERVELD	385	85.50%	56	4.9%	291	82.10%	52	7.0%

From Table 14 it is clear the A1 response performance in percentages and the number of calls with a response time over 15 minutes per municipality are two different things. Although the response performance is the highest in Emmen (in 2011), there are also the most number of calls with a response time over 15 minutes in Emmen. The municipalities Emmen, Coevorden, Hoogeveen, and Assen have the largest amount of A1 calls with a response time over 15 minutes. As consonant with theory; high efficiency gains can thus be obtained by focussing on high risk or non-rural areas where most of the calls for assistance occur.

In the next figures the focus will be on the amount of calls that exceeded the 15 minutes limit to locate their specific location. Figure 17 shows the locations and number of calls that had a response time over 15 minutes. The location is indicated by a square red box. The background colour is related to the amount of calls that exceeded the 15 minutes response time in that area. The interpretation is provided below:

Figure 17a) Below 5 calls is green, above 10 calls is red, everything in between changes from green to red.

Figure 17b) Below 40 calls is green, above 80 calls is red, everything in between changes from green to red.

a) Calls with response time >15 min (Grid 100x100) b) Calls with response time >15 min (Municipality)

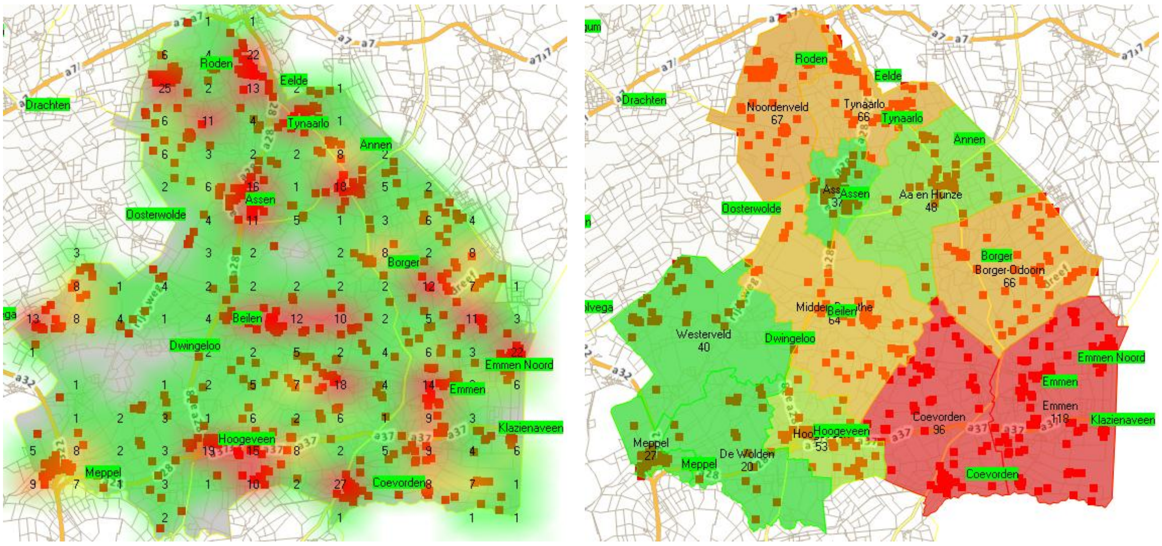


Figure 17 a-b) Amount of A1 calls > 15 min response time (Data: UMCG ambulancezorg, 01-01-2010 – 19-10-2010)

Although from figure 16 it seemed that the response performance was better in the cities (higher A1 response performance in percentages), the calls with a response time over 15 minutes are actually pretty dispersed throughout the region with some emphasis on:

- The south-east of Drenthe (area around Emmen and Coevorden)
- The rural area between Hoogeveen, Beilen, and Emmen
- The north of Drenthe (Roden, Tynaarlo)
- All larger places

Striking is that many calls are well within the reach of the nearest base.

5.2.2 Demand and A1 performance by time

To detect if there are specific demand patterns and associated A1 response performance patterns for different time segments the demand and A1 response performance is analysed per month, day, and hour.

Demand and A1 performance per month

In Figure 18 the total historic demand for different EMS and the response performance in Drenthe is displayed per month for the years 2010 and 2011.

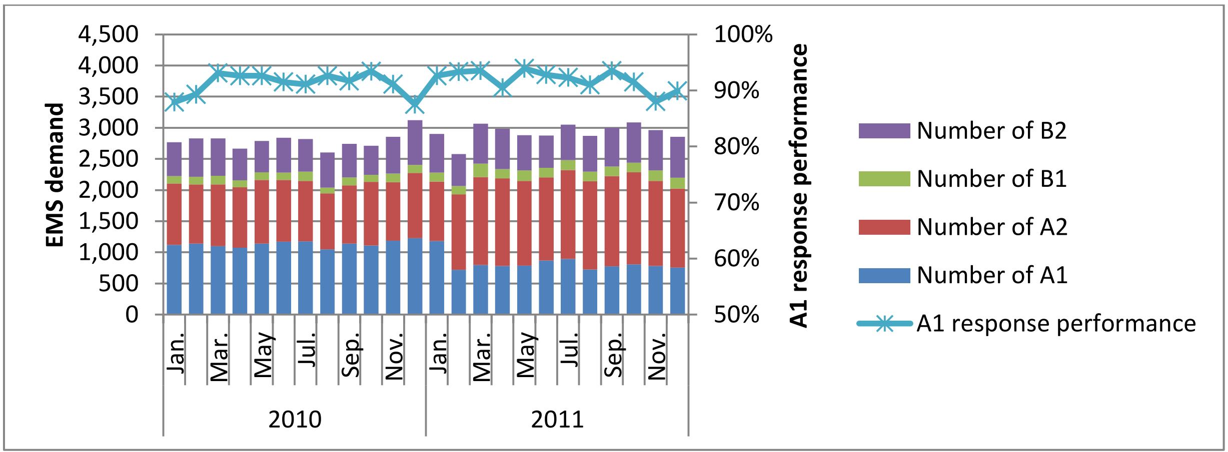


Figure 18 Demand for EMS and A1 response performance in Drenthe per month (Dundas, 2010-2011)

From Figure 18 it can be observed that demand for EMS does fluctuate a bit between months, but that there is no clear seasonal pattern. From February 2011 there is a drop in the number of A1-priority calls and an increase in A2-priority calls. This change is due to changes in the priority dispatching in the control centre. The increase in demand and decrease in A1 response performance in December 2010 is caused by heavy snowfall.
Based on Figure 18 there is no need for different monthly schedules. When specific (weather) conditions demand additional resources (for example heavy snowfall in December 2010), then the schedule might be adjusted accordingly.

Demand and A1 performance per day

Figure 19 displays the average demand for different EMS on different days.

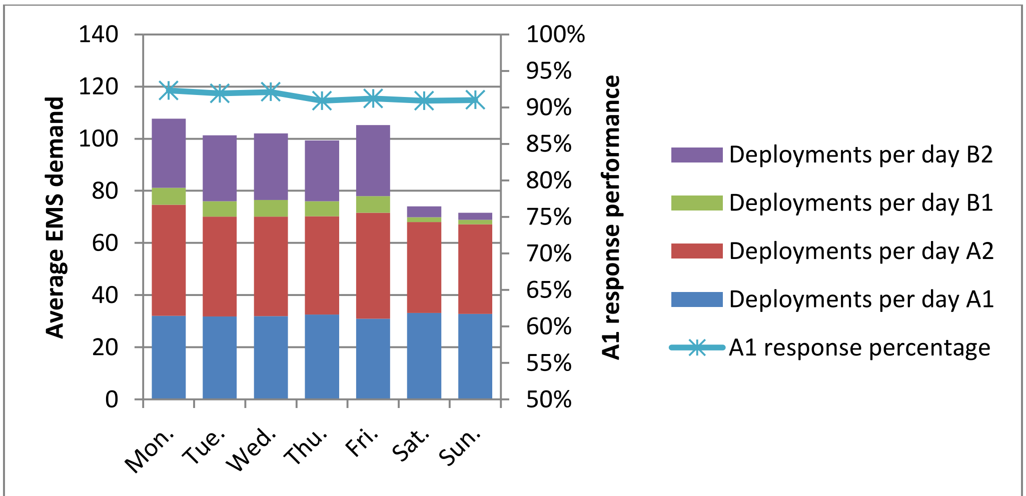


Figure 19 Average demand per day stacked by call class and A1 response performance (Dundas, 2010 -2011)

Based on Figure 19 there seems to be no significant differences in the average demand per day for the urgent calls (A1 blue, and A2 red). Ordered transport (B1 and B2) is mainly on weekdays and in much lesser degree in the weekend. Urgent demand (A1, A2) can considered to more or less cyclic with a period of one day. Total EMS demand (A1, A2, B1, and B2) can considered to be cyclic with a period of one week.
The average A1 response performance does not show large fluctuations over the different days.

Demand and A1 performance per hour
Figure 20 displays the average demand per hour for different EMS throughout the day for weekdays. Figure 21 displays the average demand per hour for different EMS throughout the day for weekends. In both figures the corresponding A1 performance is also displayed.

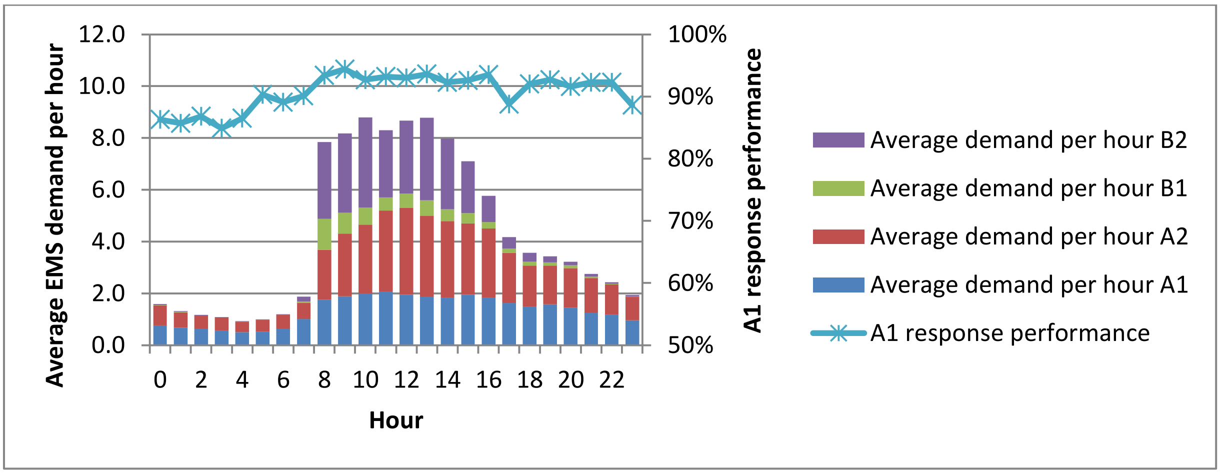


Figure 20 Weekdays: demand per hour (stacked by call priority) and A1 response performance (Dundas, 2010 -2011)

Weekdays:
- Demand for ordered transport (B1 and B2) is typically between 08:00 and 17:00 on weekdays
- Urgent demand is low at night, high at day-time (08:00 – 17:00) reaching its peak around 12:00 and decreases in the evening.
- A1 response performance is lower at night (after 23:00)
- There is a sudden drop in the A1 response performance between 17:00 and 18:00.

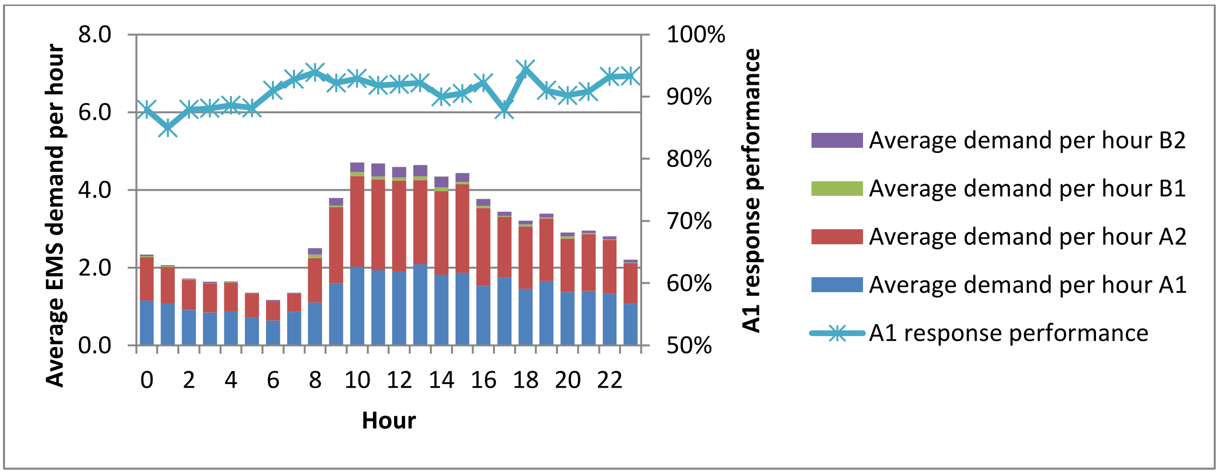


Figure 21 Weekend: demand per hour (stacked by call priority) and A1 response performance (Dundas, 2010 -2011)

Weekends:

- Urgent demand is a bit more constant throughout the day compared to weekdays.
- Urgent demand is a bit higher in the early hours of the night compared to weekdays.
- Urgent demand is low at night, high at day-time (08:00 – 17:00) and steadily decreases in the evening.
- A1 response performance is higher at daytime and in the evening compared to at night.
- There is a sudden drop in the A1 response performance between 17:00 and 18:00.

Percentage of total A1 calls with a response time over 15 minutes per day and hour

In the past few figures the demand for EMS and A1 response performance was displayed for different time units. It is also interesting to see which time segments contribute the most calls to the total calls with a response time over 15 minutes. This section addresses which hour of which day contributes which percentage of total A1 calls with a response time over 15 minutes.

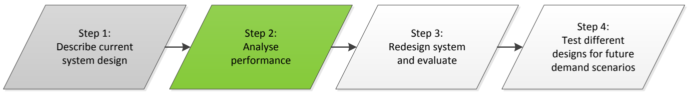
Each entry in Table 15 is calculated as follows:

$$\frac{Number\ of\ A1\ calls\ with\ a\ response\ time\ over\ 15\ minutes\ for\ day\ x\ and\ hour\ y}{Total\ number\ of\ A1\ calls\ with\ a\ response\ time\ over\ 15\ minutes}$$

The more red the cell, the larger the contribution to the total A1 calls with a response time over 15 minutes.

Table 15 Percentage of total A1 calls with a response time over 15 minutes per day per hour (Dundas, 2010-2011)

Hour\Day	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Total
0	0.4%	0.8%	0.3%	0.6%	0.5%	0.5%	0.9%	4.1%
1	0.6%	0.3%	0.5%	0.5%	0.5%	0.7%	1.0%	4.2%
2	0.2%	0.4%	0.6%	0.4%	0.5%	0.4%	0.7%	3.3%
3	0.6%	0.4%	0.3%	0.3%	0.5%	0.4%	0.6%	3.2%
4	0.3%	0.2%	0.2%	0.4%	0.4%	0.3%	0.7%	2.8%
5	0.2%	0.1%	0.1%	0.2%	0.6%	0.6%	0.3%	2.2%
6	0.3%	0.3%	0.5%	0.3%	0.3%	0.2%	0.3%	2.4%
7	0.5%	0.7%	0.3%	0.7%	0.2%	0.4%	0.2%	3.2%
8	0.7%	0.6%	0.5%	0.6%	0.6%	0.3%	0.4%	3.7%
9	0.3%	0.6%	0.6%	0.8%	0.4%	0.6%	0.7%	4.0%
10	0.6%	0.7%	0.5%	0.7%	1.2%	0.7%	0.7%	5.3%
11	0.4%	0.8%	0.5%	0.9%	0.8%	0.6%	1.0%	5.3%
12	0.7%	0.5%	0.6%	0.8%	0.8%	0.8%	0.8%	5.1%
13	0.4%	0.6%	0.6%	0.7%	0.7%	1.1%	0.5%	4.8%
14	0.6%	0.6%	0.9%	0.8%	0.7%	1.3%	0.5%	5.5%
15	0.6%	0.9%	0.5%	1.0%	0.7%	1.0%	0.8%	5.6%
16	0.6%	0.6%	0.7%	0.6%	0.5%	0.5%	0.7%	4.3%
17	1.0%	0.5%	1.6%	0.7%	0.8%	1.2%	1.0%	6.9%
18	0.8%	0.6%	0.5%	0.4%	0.7%	0.5%	0.3%	3.9%
19	0.4%	0.5%	0.6%	0.7%	0.7%	0.7%	0.8%	4.5%
20	0.6%	0.6%	0.6%	0.9%	0.3%	0.6%	0.8%	4.5%
21	0.3%	0.6%	0.4%	0.7%	0.4%	0.7%	0.6%	3.8%
22	0.7%	0.4%	0.3%	0.5%	0.4%	0.7%	0.2%	3.3%
23	0.4%	0.7%	0.4%	0.6%	0.6%	0.5%	0.2%	3.6%
Total	12.8%	13.4%	13.1%	15.3%	14.3%	15.7%	15.3%	100.0%



From Table 15 it can be observed that in general there are no time segments that perform extraordinary worse than other time segments. All hours contribute between 0.2 and 1.6% of the total calls with a response time over 15 minutes. Some notable points are:

- Most calls with a response time over 15 minutes are on Saturday 15.7% (especially at daytime) and Sundays 15.3% (especially at daytime and in the early morning).
- Most calls with a response time over 15 minutes are at daytime between 10:00 and 18:00.
- The hour between 17:00 and 18:00 contributes the largest amount to the total calls with a response time over 15 minutes.

5.2.3 Demand and performance by location and time

Ideally, we would also like to see whether or not the local performance changes over time. We would like to if there are:

- seasonal differences for the location of A1 calls with a response time over 15 minutes; and
- day part difference for the location of A1 calls with a response time over 15 minutes.

Graphical call data is only available for 01-01-2010 to 19-10-2010. This is not enough data to detect any seasonal differences over the years. We have already seen that heavy snowfall can significantly worsen the response performance.
To determine whether the location of A1 calls with a response time over 15 minutes changes over the day, the days are separated into:

- weekdays; and
- weekends.

These two types of days were divided into three equal time segments:

- 00:00 – 08:00
- 08:00 – 16:00
- 16:00 – 24:00

This resulted in six combinations. The main findings are presented in Table 16.

Table 16 Main findings location of calls with a response time over 15 minutes by type of day and time segment (Data: 01-01-2010 – 19-10-2010)

Type of day	Time segment	Weak areas (location of A1 calls with > 15 min response time)
Weekdays	00:00 – 08:00	1. The North: (Tynaarlo, Eelde) 2. Rural area between Hoogeveen, Beilen, and Emmen 3. To the south-east of Borger
	08:00 – 16:00	1. Larger places: Roden, Assen, Emmen, Coevorden, Hoogeveen, and Meppel 2. Rural area between Hoogeveen, Beilen, and Emmen
	16:00 – 24:00	1. The North: (Tynaarlo, Roden, Eelde) 2. Larger places: Assen, Emmen, Coevorden, Hoogeveen, and Meppel
Weekends	00:00 – 08:00	1. Rural area between Hoogeveen, Beilen, and Emmen
	08:00 – 16:00	1. The North: (Tynaarlo, Roden, Eelde) 2. Coevorden, Hoogeveen, Meppel
	16:00 – 24:00	1. To the south-east of Borger 2. The North: (Tynaarlo, Eelde) 3. Hoogeveen

5.2.4 Overview demand and A1 response performance

Demand overview

- There are no clear differences in demand between different months.
- Urgent demand is unpredictable in the short-term. However it behaves in a more or less cyclic matter of one day. In the long-term, specific trends can be detected where demand is high at daytime and decreases gradually in the evening and remains relatively stable and low at night.
- Demand for ordered transport is unpredictable in the short-term. In the long run, it behaves in a cyclic matter of one week. Demand for ordered transport is typically between 08.00 – 17.00 on Mondays to Fridays.

Based on historic grounds, there are no strong suggestions to make different schedules per season or month. However, there are a few differences between weekdays, Saturdays and Sundays. The demand analysis as performed in section 5.2 is a general demand analyses for the whole region Drenthe. Small regions may deviate from this general demand pattern.

A1 performance overview

First of all, there are no exceptional bad regions or time segments regarding the A1 response performance. However, there are a number of areas and time segments that deserve special attention.

<u>Performance based on location</u>

- The calls with a response time over 15 minutes are pretty dispersed throughout the whole region with some emphasis on
  - The North (Tynaarlo, Roden, Eelde)
  - The larger places
  - The rural area between Hoogeveen, Beilen, and Emmen
- In general, most calls with a response time over 15 minutes are well within the reach of the nearest base

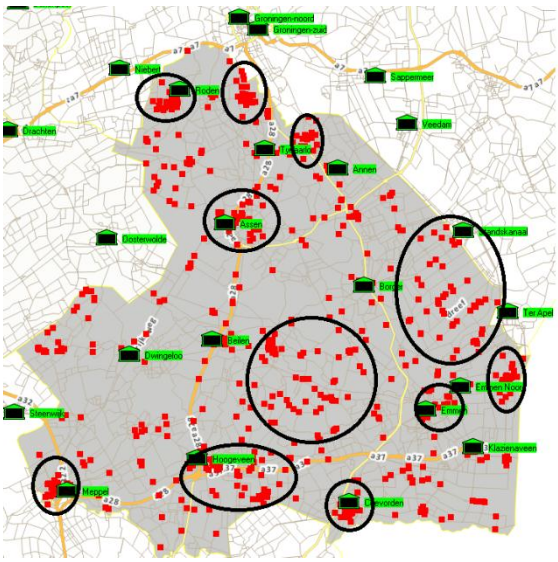


Figure 22 Number of calls with a response time over 15 minutes. Data: (01-01-2010 – 19-10-2010)

Performance based on time:

- The A1 response performance in percentages is lower at night
- Most of the calls with a response time over 15 minutes are in the weekends
- Most of the calls with a response time over 15 minutes are at daytime
- Between 17:00 and 18:00 there was a sudden drop in the response performance (for all days)

Performance based on location and time:

- There were no large differences in performance based on location and time segment of the day. Most important areas are still:
    - The North (Tynaarlo, Roden, Eelde)
    - The larger places
    - The rural area between Hoogeveen, Beilen, and Emmen

5.3 Cause and effect analysis

In the problem analysis (see appendix B) it was identified that two main causes for A1 calls to have a response time over 15 minutes were:

- Driving distance to far from current location of the vehicle
- Outside own working area, i.e. nearest vehicle was not available

In this section the aim is to provide a more detailed explanation of these causes by linking the A1 response performance as identified in section 5.2 to the current interpretation of the four design parameters. It is divided into two parts:

- Static EMS system: a feasibility test is conducted to analyse the reach of different bases in order to determine which areas can be covered. (5.3.1)
- Dynamic EMS system: the dynamic effects of vehicles being dispatched to calls is analysed in order to determine how the current interpretation of the four design parameters affects the availability to calls. (5.3.2)

5.3.1 Static EMS system: a feasibility test

This section analyses the static feasibility to cover areas in Drenthe. Figure 23 shows all the ambulance stations in Drenthe and in the surrounding provinces. All roads in Figure 23 have a colour. The colour indicates the driving distance from the nearest base when the ambulance is driving with lights and sirens. A green road indicates that it can be reached within 11 minutes, yellow between 11 and 12 minutes and red means longer than 12 minutes driving time. The 12 minutes reach of each base is indicated by an oval in Figure 23b.

a) Number of A1 calls (Grid 100x100) b) Driving reach from base (12 minutes)

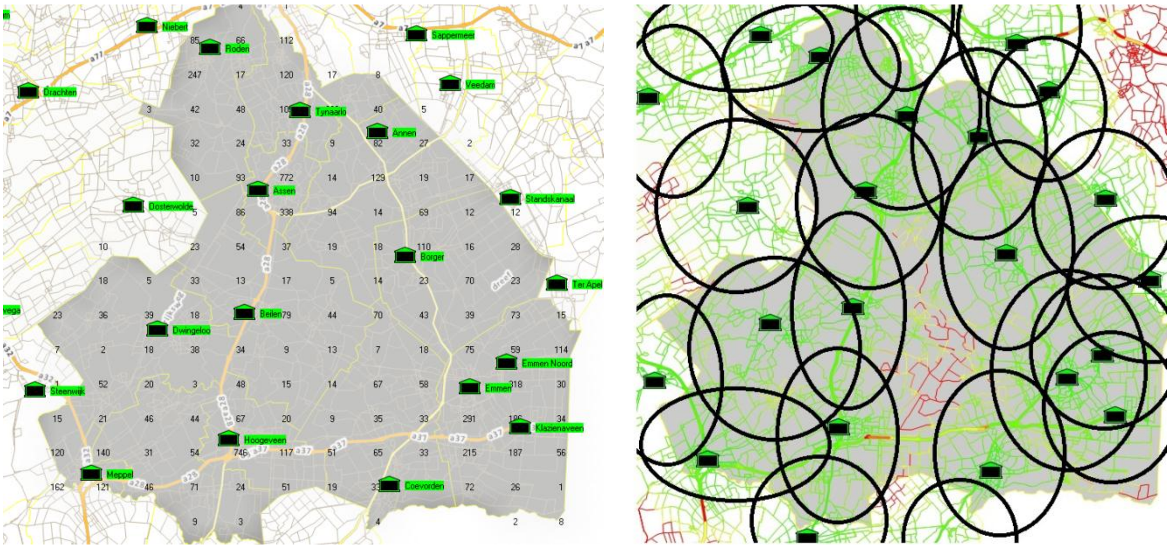


Figure 23
a) Amount of A1 calls per grid (Data: UMCG ambulancezorg, 01-01-2010 - 19-10-2010)
b) 12 minutes driving range from base with lights and sirens

Observations:
Most areas are green and easy to reach from the nearest base. There are, however, a few areas where the roads are coloured red. This means that such an area is not likely to be reached within a 12 minutes travel time from the nearest base. These areas are:

- A large area in the centre of Drenthe.
- A small area to the south of Roden
- A small area to the south of Klazienaveen
- In the evenings, nights and weekends there is no vehicle available at the base Tynaarlo. When there is no shift in Tynaarlo, there is a small area that cannot be reached, especially at night.

At night, these areas are a bit larger since the driving limit is then 11 minutes instead of 12 minutes due to a longer mobilisation duration.

Conclusions:

- The small areas to the south of Roden and Klazienaveen are too small to be significant.
- To only have a dayshift in Tynaarlo decreases the feasibility for a small area and might affect the A1 response performance. In section 5.2 it was identified that the North was one of the areas where there were many calls with a response time over 15 minutes, especially in the evenings, nights, and weekends.
- Not covering the centre of Drenthe explains why this rural area has such a low A1 response performance. In this area in the centre of Drenthe that is coloured red in Figure 23, there were 58 calls with a response time over 15 minutes from the 9644 A1 calls in Drenthe that were used for this analysis. This is (58/9644)*100%= 0.60%.

5.3.2 Dynamic EMS system: the availability of vehicles

In reality vehicles are dispatched to calls which affects the availability to future calls. When the nearest base cannot respond to a call, a vehicle from a different base it dispatched to the call. This leads to vehicles operating outside their own working area which possibly results in a call with a response time over 15 minutes because of the longer driving distance. This section analyses in what way the current interpretation of the four design parameters contributes to this cause.

In order to understand the dynamic aspects of an EMS system, first some general considerations regarding the probability of another EMS demand for different arrival rates are addressed. Thereafter the performance is analysed based on the four design parameters:

1. the number and locations of stations;
2. EMS resource schedule: i.e. the number of different types of vehicles to deploy at each base and at what times they should operate;
3. dispatching policies; and
4. relocation strategy: i.e. how and when to re-deploy resources under different system states.

Possible causes and their effect on the total A1 performance are identified and quantified were possible in order to assess the importance of that particular cause.

Probability next EMS demand for different arrival rates

This section serves to obtain an understanding of the relationship between arrival rates, number of vehicles and availability of vehicles. After this theoretical section has been addressed, each of the four design parameters will be discussed with the findings of this section in mind.

EMS demand is highly unpredictable in the short-term, but in the long-term some patterns can be identified. Arrival rates can be calculated by counting the demand per hour that each base served from 2010 to 2011. If we assume that at t=0 there is a demand for EMS, and the arrival rate is known, the possibility of another arrival within the next hour can be calculated. Since the time between patients is independent, a Poisson distribution can be used to calculate the possibility of x or more patients demanding EMS within a specific time period. Since on average an ambulance team is occupied for one hour serving a call, it is appropriate to calculate the possibility that x or more patients demand EMS within the next hour. The probabilities for different arrival rates are provided in Table 17. Table 18 provides some examples of arrival rates including A1, A2, and B1 calls in 2011. An explanation of the Poisson distribution and a complete table of historic arrival rates for different stations can be found in Appendix H and I respectively.

Assumptions for interpreting Table 17:

- At t=0 all vehicles are available
- At t=0 there is a demand for EMS
- Service time is 1 hour
- A patient cannot be served within a 15 minutes response time when the area is not covered

Table 17 Probabilities x or more patients demand EMS for different arrival rates

Probability of failure if:	Probability demand for EMS	Arrival rate (calls per hour) 0.05	0.1	0.2	0.3	0.4	0.6	0.8	1	1.2
	No patients	95.1%	90.5%	81.9%	74.1%	67.0%	54.9%	44.9%	36.8%	30.1%
Initially covered once	1 or more patients	4.9%	9.5%	18.1%	25.9%	33.0%	45.1%	55.1%	63.2%	69.9%
Initially covered twice	2 or more patients	0.0%	0.0%	0.1%	0.4%	0.8%	2.3%	4.7%	8.0%	12.1%
Initially covered three times	3 or more patients	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.9%	1.9%	3.4%

Table 18 Examples of arrival rates in Drenthe

Arrival rates	Examples (A1,A2,B1)	Examples (only A1)
0.05	Dieverbrug/Annen at night	One vehicle posts at night
0.1	Klazienaveen/Roden at night	One-vehicle posts at daytime Multiple vehicle posts at night
0.2	Dwingeloo/Tynaarlo/Beilen at day time, Emmen/Hoogeveen at night	Hoogeveen at daytime
0.3	Klazienaveen/Coevorden/Roden at day time, Assen at night	Assen, Emmen at daytime
0.4	Emmen/Hoogeveen evening	--
0.6	Hoogeveen at day time	--
0.8	Emmen late afternoon	--
1	Assen/Emmen at day time	--
1.2	Assen at bussiest point	--

Examples

1. Area that is initially covered by one vehicle

If an area is covered by only one vehicle and this vehicle has just been dispatched to another call, there is some probability of one or more patients demanding EMS while the vehicle is not available. Every next patient that needs urgent A1 EMS cannot be served within the specified response time. For an arrival rate of 0.2, there is an 18.1% probability that there will be one or more patients demanding EMS within the hour. Therefore with the assumption for interpreting Table 17, it is expected that the response performance will only be 81.9% in such an area.

2. Area that is initially covered by two vehicles

However, if the area in the example above is covered by two vehicles, then the next patient demanding EMS can be served by the second vehicle and we only have a problem when there will be two or more patients. Since the probability of arriving two or more patients is much lower than the arrival of one or more patients for these arrival rates, the probability that there will be a response time over 15 minutes can be significantly reduced by covering an area twice. In this case the probability of a patient not being reached within a 15 minutes response time is only 0.1%. Note that this example is overly optimistic since it assumes the second vehicle is available. This can be compensated by incorporating a busy factor. If we assume the second vehicle is busy 30% of the time, the expected coverage can be approximated by the following calculation: 1- (0.3*18.1% + 0.7*0.1%) = 94.5%.

Note that when an area is covered twice, the arrival rate can be much more than twice as large to achieve the same availability as for an area that is covered once. These pooling effects make it far more efficient to cover high demand areas.

Practical implications

- Increasing the availability of vehicles can improve the A1 response performance, especially where the probability for EMS is the largest
- Increasing the multiple coverage of areas can improve the A1 response performance, especially where the probability for EMS is the largest
- It is far more cost-efficient to cover high demand areas because of pooling effects

The number and locations of stations

This section aims to link the number and locations of stations to the identified 'problem' areas of section 5.2 with the theoretical section from above in mind. The number and location of stations do not only determine which areas are covered in terms of driving distance (see section 5.3.1.), they also determine how well areas are covered. In the current design, some areas are covered by just one station, while other areas are covered by two or three stations. From the theoretical discussion above it is clear that covering areas by more than one station can significantly improve the response performance, especially for higher arrival rates. However, increasing the expected coverage can both be obtained by additional shifts as additional stations or moving stations.
To recall the problem areas as identified in section 5.2:

- The North (Tynaarlo, Roden, Eelde)
- The larger places
- The rural area between Hoogeveen, Beilen, and Emmen

In the North there is some overlap between the bases. The base Tynaarlo can also reach Assen, Annen and a large part of Roden. Except for Roden, these bases are all located near highways or fast roads in order to reach an area outside their own working area. It is therefore not expected that the expected coverage can be increased by relocating stations.
The areas that are covered by just one station are mainly in the centre of Drenthe; i.e. the area around the not covered rural area as identified in section 5.3.1. For low arrival rates, this will not have a large impact on the A1 response performance. However, also parts of Meppel, Hoogeveen and Coevorden are just covered by these stations itself. This is likely to have an impact on the A1 response performance. In these cities, the probability for another EMS demand is higher than in rural areas and therefore not covering these areas by multiple vehicles will affect the A1 response performance. In Hoogeveen and Meppel there is an additional day-shift that provides this double coverage. This will be addressed in the next section (EMS resource schedule). In Coevorden there is only one ALS vehicle. The historic arrival rate for A1, A2, and B1 demand is around 0.2-0.3 at daytime in the area around Coevorden. When Coevorden is only covered by one ALS vehicle at the base Coevorden, the expected coverage is only 74.1% to 81.9% for these arrival rates. The achieved A1 response performance for the municipality Coevorden was 85.5% and 87.3% for the years 2010 and 2011 respectively. The difference between the expected coverage and the achieved A1 response performance is partly caused by the fact that in reality a part of Coevorden is covered by the base Emmen and the province Overijssel. Although the achieved A1 performance is a bit higher than the expected performance based on Table 17, the A1

performance is still relatively low compared to other places in Drenthe. This can be attributed to the fact that a large part around the base Coevorden is only covered by the base Coevorden. Stations like Emmen or Klazienaveen are not considered to be at strategic locations to provide coverage for Coevorden.
It cannot be determined how many calls could have been reached within the specified response time when stations were sited at different locations in order to provide better coverage for other stations. When stations are relocated, it is likely that at some places the expected coverage increases, while at other places the expected coverage decreases.

EMS resource schedule

In this section the current match between supply and demand will be discussed. Possible causes for calls to have a response time over 15 minutes that relate to the EMS resource schedule are identified and quantified were possible.
First the deployment system is discussed. Besides the deployment system, the following aspects will be analysed to determine whether there is a good fit between supply and demand:

- Utilization rates of different stations
- Workload per day and hour
- Shifts

<u>Deployment system</u>
In Drenthe there is a tiered system with ALS vehicles, BLS vehicles and Rapid responders. In chapter 3 other deployments systems were mentioned. Therefore one possible option is that the current deployment system is not optimal for Drenthe. In chapter 3 it was described that tiered systems were especially suited for large urban areas. Since Drenthe is not considered to be a large urban area, a tiered system might not be suited here. It cannot be said which deployment system is most suited for Drenthe and the effects on the A1 response performance cannot be quantified.

<u>Utilization rates of different stations</u>
The workload of the different vehicles and stations should also be considered to determine whether the division of workload between different bases and vehicles is equal and to determine whether the resource is justifiable. When the utilization is too high, it can increase the risk of occupational stress and injury to EMS personnel. (Chng et al., 2001) However, when the utilization is too low, there is a concern for potential skill degradation and the efficiency of the particular station will be low.
For every deployment the different times are registered. This includes the moment a vehicle is dispatched to a call and the moment the vehicle is again available to new calls. These deployments can be distinguished per base. This allows for calculating a utilization rate per base. It is not possible to differentiate between multiple vehicles in one base since a specific type of shift does not always use the same vehicle. Sometime a BLS shift uses an ALS vehicle, therefore the calculated utilization is an approximation of the real utilization for ALS ambulances. The utilization is calculated by dividing the total time the ALS ambulances of a base were busy serving calls by the total available time of all ALS ambulances at that base. Utilization rates for 2010 are presented in Table 19.
Note that the utilization for Eelde and Assen are not completely correct. One 24-hour shift from Assen is based in Eelde at daytime. I suspect that it is not always properly recorded to

which base a deployment belongs. This mixes up the utilization for Eelde and Assen. The true utilization for Assen should be lower and for Eelde higher; day vehicles have a higher utilization since demand is higher at daytime.

Table 19 Historic utilization 2010

Total overview 2010	Shift	Utilization
306 Annen	1x 24h	0.136
301 Assen	2x 24h	0.306
302 Beilen	1x 24h	0.143
303 Borger	1x 24h	0.155
304 Coevorden	1x 24h	0.151
307 Emmen	2x 24h*, 2x 9h (5days)	0.330
317 Emmen Noord	1x 24h*	0.132
312 Dwingeloo	1x 24h	0.093
310 Hoogeveen	1x 24h + 1x 9h	0.245
308 Klazienaveen	1x24h	0.172
311 Meppel	1x 24h + 1x 9h (5days)	0.192
313 Roden	1x 24h	0.179
998 Tynaarlo	1x 9h motor	0.074
309 Eelde	1x 9h (5days)	0.152

*One 24-hour shift from Emmen moved to Emmen-Noord in July 2010

All one-24 hour vehicle stations have pretty similar (low) utilizations (.093 to .192 Roden). Posts with more cars (Assen, Emmen, Hoogeveen and Meppel) have a higher utilization than one car posts. This is partly caused by day vehicles which have a higher utilization because of the higher arrival rates at day time. The utilization rate for the motor in the base Tynaarlo and the 24-hour post in Dwingeloo are the lowest.
Since all utilizations are pretty low, there is a lot of unused capacity. From these utilization rates I cannot state that some stations are exceptionally busy what would result in more calls with a response time over 15 minutes. Indeed, we have already seen that many of these calls are pretty dispersed throughout the whole region, therefore it was not expected that there would be large differences in the utilization rates.

<u>Workload per day and hour</u>

The utilization rates per post do not say anything about how the workload changes over time. Figures 24-26 show:

- Capacity in hours (stacked by ALS vehicles and BLS vehicles)
- Adjusted demand hours* (stacked by ALS demand (A1,A2,B1) and BLS demand (B2))
- Total utilization

* The adjusted demand hours is calculated by multiplying the average demand for that time interval with the average service time per call.

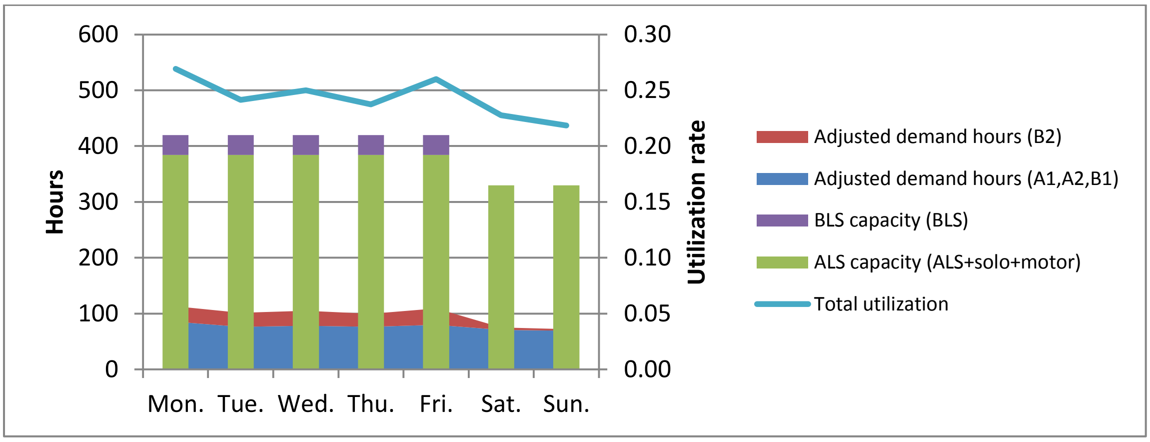


Figure 24 Demand, capacity and utilization for each day of the week (Dundas, 2011)

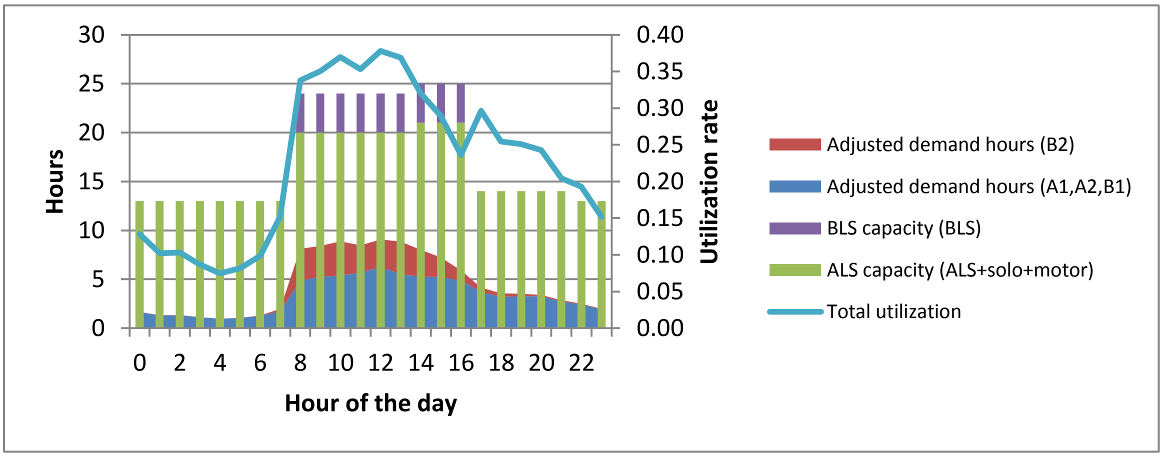


Figure 25 Demand, capacity and utilization per hour for weekdays (Dundas, 2011)

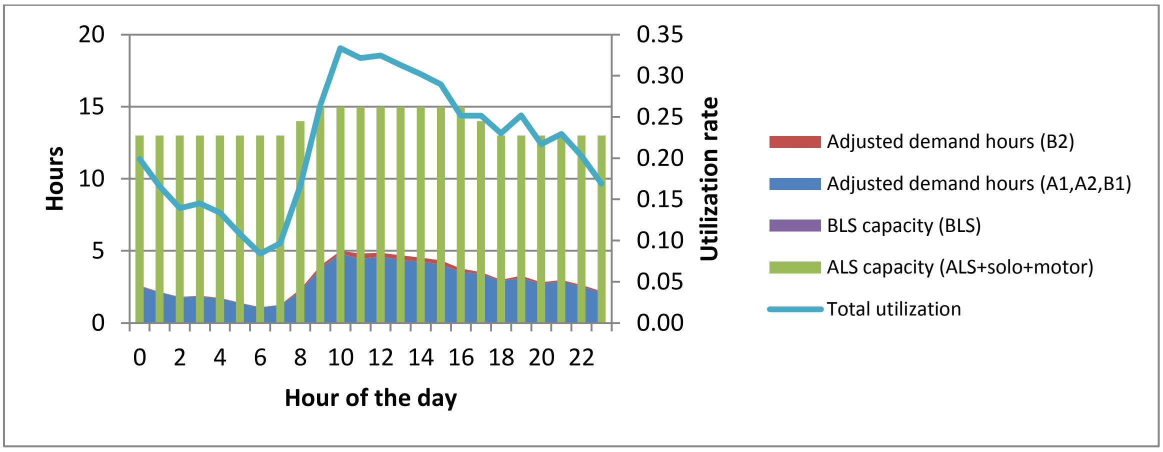


Figure 26 Demand, capacity and utilization per hour for weekend days (Dundas, 2011)

From Figure 24-26 it can be observed that:

- Utilization is pretty constant over the days but a bit lower in the weekend
- Utilization is much higher at daytime
- There is a drop in the utilization followed by a peak around 17:00 hours on weekdays

A number of day shifts end at 17:00 causing the utilization to rise after 17:00. This may partly cause the dip in the A1 response performance between 17:00 and 18:00.

In Table 15 it was calculated that 6.9% of all A1 calls with a response time over 15 minutes occurred between 17:00 and 18:00. While only 4.3% and 3.9% occurred between respectively 16:00 and 17:00 and 18:00 and 19:00. Taking the average of these surrounding hours (4.1%) than the volatility between supply and demand may cause the response time to be over 15 minutes for (6.9%-4.1%)*(1-92.3%) = 0.22% of all the A1 calls. Note that this volatility between supply and demand is a possible explanation; it may also be (partly) caused by traffic jams.

<u>Shifts</u>

Day shifts on weekdays start at 08:00 and stop at 17:00. Since the expected coverage depends on the number of vehicles that are able to serve an area, a distinction is made based on these start and end-times. From section 5.2 we have seen that the North, the rural area and the larger places are the main areas were in absolute numbers the most calls have a response time over 15 minutes. The rural area has already been addressed. The North and the larger places will be addressed here.

1. Day time (08:00 – 17:00)

Larger places: Emmen, Assen, Hoogeveen, Meppel, Coevorden

Directly around the bases Emmen, Assen, Hoogeveen and Meppel the A1 response performance is around 98%. Since the volume of calls is that high in the cities, these cities still have the largest amount of calls with a response time over 15 minutes in Drenthe. Even though these bases are covered by more than one shift, there will be situations when there is a demand for EMS and there is no vehicle available. The high arrival rates and uncertainty in demand causes situations where all vehicles in the city are busy serving calls.

Coevorden has only one shift and we have seen that a major part of the area around Coevorden is only covered by the base Coevorden. At daytime when the arrival rate is the highest, the area around Coevorden is more vulnerable.

BLS shifts

We have also seen that there is only one BLS vehicle in Emmen, while there are two BLS vehicles in Assen. B2 demand is the highest in Emmen, therefore having only one BLS vehicle in Emmen may have a negative effect on the A1 performance in this area. Especially when B2 demand is higher since there is a weak negative but significant relationship between BLS demand and A1 performance on weekdays. For more on the relationship between demand and A1 performance see Appendix G.

2. Evening and night (17:00 – 08:00)

The North:

At Tynaarlo there is only an ALS dayshift on weekdays. Besides this ALS there is a motor dayshift 7 days a week. However this motor does not remain at the base during its shift. Therefore, the area around Tynaarlo is less covered on evenings, nights, and weekends than displayed in Figure 23. Although there is only a very small area that falls outside the 11 minutes driving range at night, there is a pretty large area that can only be covered by one station. The bases, Assen, Roden and Annen are less covered when there is no shift in Tynaarlo. In total there were 117 A1 calls with a response time over 15 minutes in the North (Roden to Annen) in the evenings, nights and weekends. This is (117/9644)*100%= 1.2% from the 9644 A1 calls that were used for this analysis. It must be stressed that it cannot be said that not having a resource in Tynaarlo will be the only cause of a response time over 15 minutes for these calls. It does, however, provide an indication.

The larger places:
In the evening and nights all stations except for Assen have only one ALS vehicle. Especially the areas in the cities that are covered by one station are vulnerable in the evening since the arrival rate is still moderate in the evening. Hoogeveen and Meppel are such places.
At night, the arrival rate is pretty low and therefore this will not cause many calls with a response time over 15 minutes. From section 5.2 it was observed that the A1 response performance is lower at night. This can be attributed to both a shorter driving range and the fact that areas are less covered by multiple vehicles because there are fewer shifts.

Dispatching policies

In this section possible causes that relate to the dispatching policies are identified and quantified were possible. There are four possible causes related to the dispatching policies that may affect the A1 response performance:

1. Reroute-enabled dispatching is not executed correctly
2. Rapid responders are not dispatched affectively
3. ALS vehicles are too often sent to lower priority calls
4. There is a closest dispatching protocol

These possible causes are elaborated below.

1. In Chapter 4 we have seen that there is a closest with reroute-enabled dispatching protocol for A1 priority calls. From experience it is known that this protocol is not always executed correctly. ALS vehicles on their way to lower priority calls are not consistently reassigned to A1 calls when they are the closest unit. It is not possible to quantify this effect. However, it is known that reroute-enabled dispatching can significantly improve the response time for urgent calls. (Lim et al., 2011)
2. The protocol describes that the rapid responder should be sent to the call when it is the closest unit. Like with the reroute enabled dispatch it is known that this protocol is not always followed. Since there are only three rapid responders in the EMS system this is not likely to have a large effect on the A1 response performance.
3. ALS vehicles are too often sent to lower priority calls; this decreases their availability for urgent A1 calls. Many stations only have one ALS vehicle. When this vehicle is sent to a lower priority call, this vehicle will not be available for a possible A1 call. For lower priority calls, ambulances have a larger time window and do not have to come from the nearest base in order to be on time. Therefore, adjusting the service range that vehicles can respond to of particular vehicles enlarges the availability of these ALS vehicles. When these vehicles are available in the areas where the probability of another EMS demand is the highest, this can positively affect the A1 response performance. It is not possible to quantify this effect, since using an ambulance from another station negatively affects the performance for the area around that station. Because of this trade-off, it is not expected that the A1 response performance will be significantly affected by adjusting the service range of ambulances.
4. A closest dispatching protocol minimizes the respond time for the current call but neglects overall response performance. For areas that are covered by just one station there is little choice in deciding which unit to send to the call. For areas that are covered by multiple stations, there is a decision which may affect the total A1 response performance. Since there is relatively little overlap between stations, it is not expected

that this protocol will have a high impact on the A1 response performance. It is, however, not possible to quantify its expected impact.

Relocation strategy

In this section possible causes that relate to the relocation strategy are identified and quantified were possible. In 2010, there were only 59 'voorwaardescheppende ritten'. (Dundas) So although the objective is to cover the HEMA cities, in practice there are relatively few vehicles relocated. Many bases in Drenthe are one-vehicle posts. When there is a call in an area around such a base and the vehicle is busy, the ambulance has to travel from another base. These calls are likely to have a response time over 15 minutes. A better relocation strategy might provide better coverage for possible A1 calls. However, since many posts are one-vehicle posts, it might be difficult to decide which base should deliver a vehicle to the empty base. For a relocation strategy to work, the vehicles should be near the places where the probability of a call is the largest. This means that a vehicle should be relocated from a smaller place to the city when all the vehicles in the city are busy. If such a relocation strategy is followed, the performance in the cities will increase, while the performance in the smaller towns will decrease.

There were 210 calls with a response time over 15 minutes directly in and around the cities Emmen, Assen, Hoogeveen and Meppel. This is (210/9644)*100%= 2.18% of the total A1 calls used for this analysis. Although it cannot be said that an absence of a relocation strategy is the reason for these calls to have a response time over 15 minutes, it is expected that a better relocation strategy can improve the A1 response performance.

5.4 Summary

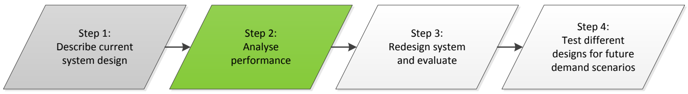
This chapter served as the second step in the research step plan and answered the research question: "What is the performance of the current EMS system and how can this performance be explained?" The main findings are presented in this section.

The A1 response performance in Drenthe is a bit below the 95% target. It was found that in percentages the response performance is the highest in the cities during daytime, while the response performance is significantly worse in more rural areas and at night. However, a response performance in percentages does not provide information about the specific number of calls with a response time over 15 minutes. Looking at the absolute number of calls with a response time over 15 minutes, it was found that there were no time segments or locations that perform exceptionally worse than other time segments or locations. In general, most of the calls with a response time over 15 minutes are concentrated in the rural area between Hoogeveen and Emmen, the North and especially the larger places at daytime. This is striking since these larger places do have the highest A1 response performance in percentages. In general there are two major findings based on this analysis:

- There is a trade-off between rural and non-rural areas. (section 5.4.1)
- There are many small causes that contribute to not achieving the A1 response performance target. (section 5.4.2)

5.4.1 Trade-off rural and non-rural areas

The following trade-off is apparent: the trade-off between the performance in the rural and non-rural areas. As consonant with literature, high efficiency gains can be obtained by focussing on high risk or non-rural areas where most of the calls for assistance occur. This focussing on high risk areas comes at the costs of performance losses in smaller towns or



rural areas where calls are less likely to occur. From the cost analysis in section 5.1 it was observed that personnel costs make up the largest part of the operational costs. These human resources should be used as efficient as possible. Therefore, when it is the objective to improve the total A1 response performance in Drenthe, the cities should receive the main priority because of their large impact on the total response performance in Drenthe.

5.4.2 List of problems, causes and impact on current A1 response performance

There is not one single large cause for not achieving the A1 response performance target in Drenthe. This section list all possible causes related to the four design parameters as identified in section 5.3. It must be stressed that this list is not an extensive list of all causes that contribute to not achieving the 95% A1 response time target and neither do these causes in reality have to play a significance role. However, it does provide an indication of what can contribute to the problem. The possible expected impact on the A1 performance is also indicated and quantified were possible. Note that the maximum expected effect is calculated, since there can be more than one cause for calls to have a response time over 15 minutes. It does only provide an indication of the expected effect. Table 20 presents an overview of the possible causes and impact on A1 response performance.

Rating importance: Expected impact on A1 response performance	
++	Very high impact
+	High impact
+-	Moderate impact
-	Low impact
--	Very low impact

Table 20 Overview possible causes and impact on A1 response performance

Parameter and possible causes for response times over 15 minutes	Problem area/time segment	Maximum effect on A1 performance	Rating importance
1. The number and locations of stations			
1.1 The rural area between Hoogeveen, Beilen and Emmen is badly covered by stations.	Rural area	=58/9644*100% = 0.60%	+
1.2 Not all stations are positioned strategically to provide coverage for other stations	Larger places	Not quantifiable	+
2. EMS resource schedule			
2.1 In Tynaarlo there is only a day shift (08.00-17.00). Therefore this area is more vulnerable in the evening and at night.	The North	(117/9644)*100%= 1.21%	+
2.2 There is only one BLS vehicle in Emmen, while B2 demand is the highest in Emmen. Therefore ALS ambulances in Emmen may serve too many B2 calls which negatively affects the A1 performance in this area.	Emmen	Not quantifiable	+-
2.3 The deployment system is possibly not optimal. (There are other deployment systems described in literature)	All calls	Not quantifiable	+-
2.4 There are not enough resources (ALS, BLS, rapid responders) to handle the simultaneously of calls.	All calls	Not quantifiable	+
2.5 All dayshifts end at the same time (17.00), this large volatility between supply and demand around this time may have a negative impact on the performance.	Peak between 17:00 – 18:00	(6.9%-4.1%)*(1-92.3%) = 0.22%	+-
3. Dispatching policies			
3.1 In practice, reroute-enabled dispatch does not happen as protocol prescribes	All calls	Not quantifiable	++
3.2 There is a closest dispatching protocol which minimizes the respond time for the current calls but neglects overall response performance.	All calls	Not quantifiable	+-
3.3 ALS vehicles are too often sent to lower priority calls; this decreases their availability for urgent A1 calls.	All calls	Not quantifiable	+-
3.4 Rapid responders are not dispatched effectively	Assen, Emmen	Not quantifiable	-
4. Relocation strategy			
4.1 There is not a good relocation strategy	Larger places	HEMA cities: (210/9644)*100%= 2.18%	++

6. SYSTEM REDESIGN AND EVALUATION

In chapter 4 and 5, the current EMS system and the current A1 response performance was described and analysed. The performance analysis resulted in a list of possible causes related to the four design parameters (location and number of stations, EMS resource schedule, dispatching policies and relocation strategy) that have an impact on the A1 response performance. In this chapter, solutions for theses causes are developed in order to redesign the EMS system in a cost-efficient way. This chapter serves as the third step in the research step plan and addresses the fourth research question: "What are the possibilities for redesigning the EMS system in order to improve the A1 response performance in a cost-efficient way?"

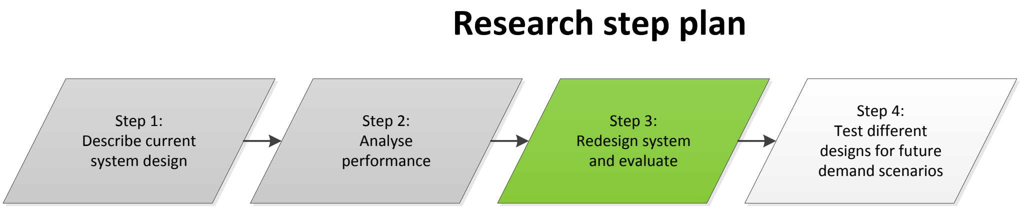


Figure 27 Research step plan: step 3

Figure 28 shows the aspects from the conceptual model that are addressed in this chapter.

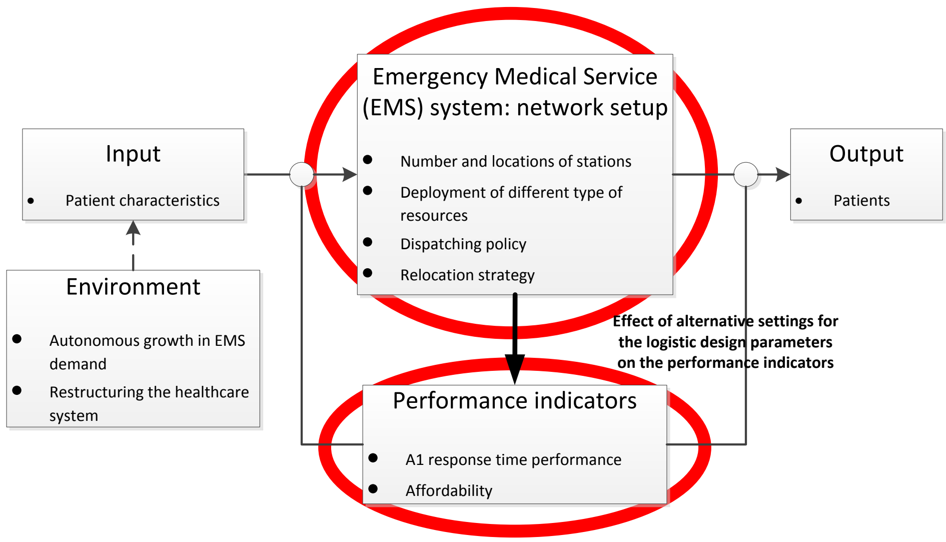


Figure 28 Conceptual model: aspects addressed in chapter 6

This chapter is constructed as follows: in section 6.1 solutions are developed for the identified causes from chapter 5. In section 6.2 a simulation tool is discussed which will be used to test different solutions. The outcomes from the first round of scenarios are addressed in section 6.3. This first round of scenarios consists of single changes from the current EMS system, based on the solutions from section 6.1. Based on the outcomes from the first round of scenarios, interesting combinations of scenarios are constructed and simulated using the simulation tool. The outcomes are presented in section 6.4. Three different solutions will be chosen for further analysis in section 6.5. A summary of this chapter is provided in section 6.6.

6.1 Creating solutions

In this section possible solutions are constructed for the identified causes that contribute to the A1 response performance problem as listed in section 5.4.

1. Number and location of stations

In the performance analysis it was identified that there is an area in the centre of Drenthe that is not covered by a station. Furthermore not all areas are covered by more than one station. These areas are vulnerable, especially when the arrival rate is high and the area is only covered by one vehicle. The following table provides an overview of the identified causes and possible solutions related to the number and location of stations.

Table 21 Causes and solution related to the number and location of stations

Identified causes	Possible solutions
1.1 The rural area between Hoogeveen, Beilen and Emmen is badly covered by stations.	• Move surrounding stations towards the uncovered area • Split surrounding (multiple vehicle) stations towards the uncovered area • Create new station in the uncovered area (needs additional vehicle)
1.2 Not all stations are positioned strategically to provide coverage for other stations	• Move stations towards exits from highways or other fast roads in order to provide coverage for other stations

2. Resource schedule

Additional resources are expensive because of the salaries for personnel. Therefore additional resources must be seen as a last resort. Small adaptions are less costly and might also improve the A1 response performance. Since the volume of calls and the utilization is lower at night than at daytime and the costs are higher, additional capacity at night is excluded from the possible solutions. Table 22 presents possible solutions.

Table 22 Causes and solutions related to the EMS resource schedule

Identified causes	Possible solutions
2.1 In Tynaarlo there is only a day shift (08.00-17.00). Therefore this area is more vulnerable in the evening and at night.	• Create additional shifts at Tynaarlo • Move surrounding stations and/or shifts closer to Tynaarlo
2.2 There is only one BLS vehicle in Emmen, while B2 demand is the highest in Emmen. Therefore ALS ambulances in Emmen may serve too many B2 calls which negatively affects the A1 performance in this area.	• Move one BLS vehicle from Assen to Emmen • Locate BLS shifts at the hospitals to minimize travel distance • Locate all BLS units in a central place (Beilen) • Create new BLS shifts
2.3 The deployment system is possibly not optimal. (There are other deployment systems described in the literature)	• Use an all-ALS system
2.4 There are not enough resources (ALS, BLS, rapid responders) to handle the simultaneously of calls.	• Add resources were there are many calls with a response time over 15 minutes (larger places)
2.5 All dayshifts end at the same time (17.00), this large volatility between supply and demand around this time may have a negative impact on the performance.	• Extent x shifts with y minutes to decrease the volatility between supply and demand

3. Dispatching policy

The A1 response performance can be improved by adjusting the dispatching policy. In the literature review in chapter 3 was identified that an EMS system can use a closest or a non-closest dispatching protocol either with or without diverting ambulances to higher priority calls. In Drenthe there is a closest with reroute-enabled dispatching protocol. However, from experience it is known that protocols are not always followed at MKNN. Likewise, rapid responders are not always dispatched to the call when they are the closest unit. Therefore the effect of different dispatching policies on the response performance should be tested. It is unfortunately not possible to test non-closest dispatching policies. It is, however, possible to test the effect of diverting ambulance to higher priority calls.
Besides executing protocols, the availability to A1 calls can be improved by keeping more ALS ambulance at their station. This can be achieved by restricting the response of certain vehicles by not sending all ALS vehicles to lower priority calls. The complete overview of identified causes and possible solutions is provided below.

Table 23 Causes and solutions related to the dispatching policy

Identified causes	Possible solutions
3.1 In practice, reroute-enabled dispatch does not happen as protocol prescribes	• Use reroute-enabled dispatching policy
3.2 There is a closest dispatching protocol which minimizes the respond time for the current calls but neglects overall response performance.	• Introduce non-closest dispatching protocol. (will not be tested)
3.3 ALS vehicles are too often sent to lower priority calls; this decreases their availability for urgent A1 calls.	• Do not send (all) ALS vehicles to the scene for lower priority calls
3.4 Rapid responders are not dispatched effectively	• Solo's only respond to A1 calls

4. Relocation strategy

From the literature review we know that it is possible to have:

- No relocation strategy
- Cover specific places
- A dynamic relocation strategy

Currently, vehicles are rarely relocated to provide coverage for another base. Since many calls are well within the reach of the nearest base, the A1 response performance can be improved by a better relocation strategy. This relocation strategy should be constructed to provide coverage for areas were the probability of another calls is the highest. Ideally, an EMS system uses a dynamic relocation model which calculates the best locations for vehicles in real-time to cover the areas where the probability of another call is the highest. With the simulation software it is not possible to have a dynamic relocation strategy. It is, however, possible to cover specific places where the probability of EMS demand is higher than other places. Covered does not necessarily mean that there should be a vehicle at the nearest base, since some bases have overlapping areas.

Table 24 Causes and solutions related to the relocation strategy

Identified causes	Possible solutions
4.1 There is not a good relocation strategy	• Cover high demand bases • Cover high demand areas

The relocation strategy will be created for 08:00 until 23:00 hours. After 23:00 hours, the arrival rates of all areas are pretty low and the costs of waking up employees to drive to another base will outweigh the potential benefits. Based on the arrival rate (Appendix I) the following order of importance is constructed: 1. Emmen, 2. Assen, 3. Hoogeveen, 4. Meppel. For all other areas the arrival rate is more or less the same.

Since Emmen can be covered by Emmen, Emmen-Noord and Klazienaveen it might be sufficient to have an ALS-vehicle in one of these three bases.

Assen can be partly covered by Tynaarlo; therefore it might also be possible to cover Assen from Tynaarlo. Covering from Tynaarlo has the additional benefit that Annen, Roden and Tynaarlo itself are covered. This Northern area was one of the problem areas as identified in the performance analysis. Extra covering this area can improve the A1 response performance in this area. Besides Tynaarlo, covering Coevorden can also yield an increase in the response performance since it was observed that Coevorden is not covered well by multiple stations.

6.2 Discrete event simulation: Optima Predict

The tool that will be used to analyse the effects of different solutions on the A1 response performance is discrete event simulation. Besides some general advantages of discrete event simulation over real life experimentation or other tools (see Appendix J), there are a number of reasons for choosing discrete event simulation in this research:

1. Incorporating all four design parameters: although there are different optimization models to determine the ‘optimal’ locations of bases and vehicles, these models cannot incorporate all aspects of an EMS system. A simulation model allows for incorporating all relevant aspects which leads to more accurate results.
2. Deal with stochastic nature of process: discrete event simulation provides the opportunity to incorporate the stochastic nature of the processes.
3. Fine granularity: Many of the constructed solutions for the identified causes are just small adjustments from the current EMS system. These identified causes and solutions are on a very high level of detail. Only a simulation model can provide an accurate estimation of the impact of these small deviations from the current EMS system.

The Optima Corporation has developed a simulation model Optima Predict which will be used in this research. The model is based on historic input data and a tuned road network. The Optima Corporation has delivered a combined baseline model of Drenthe and Friesland for 2010. For this research this baseline 2010 model is adapted to the current situation (2012) for just the region Drenthe. The reader is referred to Appendix J for a project specification including technical details of the model and information about the run length and data used.

Although the model provides a pretty accurate approximation of the real EMS system, it is still an approximation. The achieved A1 response performance in the real world seems to be better than the A1 response performance in the model. This is partly caused by the fact that in reality there is not a closed system for the region Drenthe. Other emergency medical services providers from surrounding provinces operate in Drenthe and vice versa. A histogram with a comparison of the response times shows that there is a longer right tail for the response time for the model. When extraordinary low A1 response performance is excluded from the comparison between historic data and the model, the historic A1 response performance per week is 0 to 4% better in the real world. On average the historic performance was 2.07% better in the real world. To compensate for this discrepancy in the long tail of the model, it will be assumed that the objective of 95% of the calls within a 15 minutes response time will be achieved at a level of 93% (95% - 2%) in the model. Full model validation can be found in Appendix L.

6.3 Scenarios round 1

Based on the identified problems and found solutions from step 1a, a number of scenarios were constructed with single changes from the current EMS system. The main results per identified problem are presented in Table 25. The complete list of scenarios with the response performance and average response times for A1 and A2 calls can be found in Appendix N.

Table 25 Outcome analysis for first round of solutions

Identified cause	Possible solution	Main findings
1.1 The rural area between Hoogeveen, Beilen and Emmen is badly covered by stations.	1.1a Move surrounding stations towards the uncovered area	Moving stations as Hoogeveen, Coevorden and Emmen has a positive effect on the A1 response performance. (+0.3%) Only a small part of this improvement is caused by better coverage of the rural area. See cause 1.2 for more details.
	1.1b Split surrounding (multiple vehicle) stations towards the uncovered area	Splitting Emmen or Hoogeveen only yields a fraction of the improvement in the A1 response performance (+0.1%) that would be achieved if these bases were completely relocated.
	1.1c Create new station in the uncovered area (needs additional vehicle)	A new day shift (ALS or solo) In Zweelo or Witteveen has a small positive effect on the A1 response performance +0.05% to +0.39%. This additional capacity will mainly be sucked into the cities, improving the response performance in the cities. Due to the high costs for a new shift, this solution is not costs effective.
1.2 Not all stations are positioned strategically to provide coverage for other stations	1.2a Move stations towards exits from highways or other fast roads in order to provide coverage for other stations	Like touched in 1.1a, moving stations can significantly improve the A1 response performance. (+0.26% to +0.37%) This is mainly due to better multiple coverage in the south-east of Drenthe. Moving a station does, in general, not increase the yearly operational costs making this a cost-efficient solution. Note: while moving a station can increase the A1 response performance in percentages, it can sometimes have a negative effect on the average A1 response times. Therefore, the specific location of vehicles or bases can be a trade-off between improving the worst few percent and improving the best 90%.
2.1 In Tynaarlo there is only a day shift (08.00-17.00). Therefore this area is more vulnerable in the evening and at night.	2.1a Create additional shifts at Tynaarlo	Additional shifts in Tynaarlo can strongly improve the A1 response performance (up to +0.9%). It is most cost-efficient to have an additional solo in the evenings and weekends. This yields +0.44%.
	2.1b Move surrounding stations and/or shifts closer to Tynaarlo	Moving stations towards Tynaarlo does not have a positive effect on the A1 response performance. While the performance around Tynaarlo may improve, the deteriorated performance in other areas offset this improvement.

2.2 There is only one BLS vehicle in Emmen, while B2 demand is the highest in Emmen. Therefore ALS ambulances in Emmen may serve too many B2 calls which negatively affects the A1 performance in this area.	2.2a Move one BLS vehicle from Assen to Emmen	No effect on the A1 response performance
	2.2b Locate BLS shifts at the hospitals to minimize travel distance	No effect on the A1 response performance
	2.2c Locate all BLS units in a central place (Beilen)	No effect on the A1 response performance
	2.2d Create new BLS shifts	No effect on the A1 response performance
2.3 The deployment system is possibly not optimal. (There are other deployment systems described in the literature)	2.3a Use an all-ALS system	Substituting the current four BLS to ALS vehicles improves the A1 response performance by +0.28%. This is not a costs-efficient solution due to the high costs of training personnel, salaries and new equipment.
2.4 There are not enough resources (ALS, BLS, rapid responders) to handle the simultaneously of calls.	2.4a Add resources were there are many calls with a response time over 15 minutes (larger places)	Resources (ALS or solo) were added in all larger places for weekdays 08-17, 17-23 and weekends 9-18. All effects on A1 response performance were small (0.0% to +0.25%) Due to the high personnel costs it is not cost-efficient to add ALS resources. A solo in the weekend in Emmen is the most cost-efficient solution in this category
2.5 All dayshifts end at the same time (17.00), this large volatility between supply and demand around this time may have a negative impact on the performance.	2.5a Extent x shifts with y minutes to decrease the volatility between supply and demand	ALS shifts, BLS shifts and ALS and BLS shifts were extended for 30 and 60 minutes. An extension of the ALS dayshifts of 60 minutes yielded an improvement in the A1 response performance of 0.37%. The extension of BLS shifts affected the response performance less.
3.1 In practice, reroute-enabled dispatch does not happen as protocol prescribes	3.1a Use different reroute-enabled dispatching policies	Reroute-enabled dispatching has a strong effect on the A1 response performance. Consistently reassigning ALS vehicles to A1 calls yielded an improvement of 1.28%. This is a very cost-efficient solution
3.2 There is a closest dispatching protocol which minimizes the respond time for the current calls but neglects overall response performance.	3.2a Introduce non-closest dispatching protocol. (will not be tested)	This is not tested with simulation software and will not be addressed in redesigning the EMS system.
3.3 ALS vehicles are too often sent to lower priority calls; this decreases their availability for urgent A1 calls.	3.3a Do not send (all) ALS vehicles to the scene for lower priority calls	A large number of different service range scenarios were tested. Conclusions: - Restricting the response of one car posts has a negative effect on the A1 response performance. - Restricting the response at night has a negative or no effect on the A1 response performance - Restricting the response of larger places may increase the A1 response performance, however, this is offset by a strong decrease in the performance for other services (A2,B1,B2) Restricting the service range is therefore not considered to be an effective solution
3.4 Rapid responders are not dispatched effectively	3.4a Solo's only respond to A1 calls	Restricting the response of solo's to only A1 has little effect on the A1 response performance.
4.1 There is not a good relocation strategy	4.1a Cover high demand bases	A relocation strategy was created for the bases with the highest arrival rates between 08:00 and 23:00. Covering the cities Emmen, Assen, Hoogeveen, Meppel, Tynaarlo, and Coevorden can increase the A1 response performance by 0.9%. However, many relocations are necessary to obtain this improvement resulting in many additional

		kilometres for the vehicles.
	4.1b Cover high demand areas	A relocation strategy to cover three important locations (junction Hoogeveen, junction Emmen, and Tynaarlo) in Drenthe between 08:00 and 23:00 yielded an improvement of .97%. Like mentioned at 4.1a, this solution requires a lot of additional driving hours for all personnel.

6.4 Scenarios round 2

Round 1 yielded a few attractive solutions which are combined in round 2 in order to create a design that meets the objective of an A1 response performance of 95%. This section is organised as follows: first an overview of the different solutions used for making combinations is presented. Secondly the total list of scenarios with their outcomes is discussed. At last, three different designs are chosen for further analysis.

Overview solutions used for making combinations

The different solutions with their estimated yearly costs which are used to create combinations in round 2 are presented in Table 26. For additional capacity the costs are calculated by determining the costs of personnel. For the relocation strategy, the costs are calculated by the extra kilometres the vehicles have to drive. The last column divides the improvement by the yearly estimated costs of the solutions. The higher the number, the more cost-efficient the solution is. It must be stressed that combinations of solutions can have synergy effects or may reduce the joint effects on the response time performance.

Table 26 Overview solutions used for second round of simulations

Scenario number	Scenario description	Improvement (Round 1)	Yearly estimated costs (x1000)	Improvement/ yearly estimated costs (x1000)
102	Move Hoogeveen to Hoogeveen Krakeel north	0.37	0	0
125	Move Klazienaveen to Nieuw Amsterdam (A37 exit 5 south)	0.26	0	0
127	Move Emmen to Emmen south	0.44	0	0
132	Moven Coevorden to Dalen (N854/N34 west)	0.34	0	0
206	Additional solo in Tynaarlo (Evening + weekend)	0.44	120	3.67
273	Additional solo in Emmen (Weekends)	0.25	54	4.63
284	ALS dayshifts + 60minutes	0.37	80	4.63
303	Reroute-enabled dispatching	1.28	0	0
405	Relocation strategy E,A,H,M,T (08:00 - 23:00)	0.72	86	8.37
407	Relocation strategy E,A,H,M,T,C (08:00 - 23:00)	0.9	118	7.63
421	Relocation strategy Area node Emmen, node Hoogeveen, Tynaarlo	0.97	175	5.54

Total list of scenarios round 2

Three main types of solutions are developed from the scenarios of Table 26:

1. Reroute-enabled dispatching + moving stations + relocation strategy
2. Reroute-enabled dispatching + moving stations + additional resources
3. Reroute-enabled dispatching + relocation strategy + additional resources

From each three types of solutions, one design will be chosen. This design will be tested for different future scenarios constructed in chapter 7. There is deliberately chosen to create multiple types of solutions because different types of solutions might behave differently for different future scenarios.

The total list with scenarios and their outcomes from round 2 is displayed in Table 27. The scenarios that achieved the response time target are highlighted green. The three scenarios that are chosen for further analysis are highlighted orange. Note that the response target is assumed to be met for an A1 response performance of 93% in the model. This is due to a structural underestimation of the achieved performance in the model compared to the real world as discussed in section 6.2.

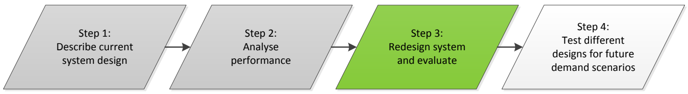
Table 27 List of scenario round 2

Scenario	Combination of scenarios	A1 %	A1 average	A2%	A2 average	yearly operational costs (x1000)
Reroute-enabled dispatching + relocation strategy						
1001	303+405	91.94	9:01	93.97	15:22	86
1002	303+407	92.39	8:57	94.33	15:18	118
1003	303+421	92.61	9:00	94.03	15.32	175
Reroute-enabled dispatching + moving stations						
1011	102+125+303	92.48	8:34	94.13	15:17	0
1012	102+127+303	92.51	9:00	94.20	15:27	0
1013	102+132+303	92.21	9:01	94.15	15:32	0
1014	102+125+132+303	92.67	8:59	94.24	15:32	0
Reroute-enabled dispatching + additional capacity						
1021	206+303	92.21	9:00	94.03	15:24	120
1022	273+303	91.70	9:24	93.93	15:27	54
1023	284+303	91.95	9:03	93.87	15:30	80
1024	206+273+303	92.26	8:59	94.14	15:19	174
1025	206+284+303	92.37	8:57	94.12	15:23	200
1026	206+284+273+303	92.58	8:54	94.17	15:18	254
Reroute-enabled dispatching + relocation strategy + moving stations						
1031	102+303+407	92.56	8:54	94.37	15:23	118
1032	125+303+407	92.60	8:57	94.33	15:28	118
1033	127+303+407	92.81	8:57	94.45	15:23	118

1034	102+127+303+407	93.09	8:52	94.53	15:27	118
1035	102+125+303+407	92.93	8:51	94.34	15:19	118
1036	102+132+303+407	93.16	8:53	94.39	15:24	118
1037	102+125+132+303+407	93.23	8:52	94.38	15:23	118
1038	102+127+132+303+407	93.10	8:55	94.51	15:25	118
1039	102+125+127+303+407	92.96	8:55	94.45	15:22	118
1040	102+125+132+303+405	93.08	8:55	94.47	15:24	86
1041	102+127+303+405	93.08	8:53	94.48	15:18	86
1042	102+125+127+303+405	92.84	8:56	94.44	15:25	86
1043	102+125+303+421	92.78	8:57	94.19	15:34	175
1044	102+127+303+421	92.63	8:59	94.35	15:34	175
1045	102+125+132+303+421	92.85	8:59	94.25	15:37	175
Reroute-enabled dispatching + moving stations + additional capacity						
1051	102+127+206+303	92.99	8:54	94.38	15:33	120
1052	102+127+284+303	92.83	8:57	94.30	15:43	80
1053	102+127+273+303	92.91	8:57	94.37	15:38	54
1054	102+132+206+303	92.86	8:55	94.24	15:25	120
1055	102+125+206+303	92.68	8:52	94.24	15:20	120
1056	102+132+125+206+303	93.31	8:53	94.29	15:26	120
1057	102+132+125+284+303	92.98	8:57	94.19	15:32	80
1058	102+132+125+273+303	92.88	8:57	94.23	15:29	54
1059	102+132+125+284+273+303	93.25	8:55	94.25	15:27	134
Reroute-enabled dispatching + relocation strategy + additional resources						
1061	206+303+407	92.72	8:54	94.27	15:14	238
1062	273+303+407	92.55	8:56	94.31	15:14	172
1063	284+303+407	92.61	8:56	94.23	15:17	198
1064	273+284+303+407	92.92	8:53	94.36	15:13	252
1065	206+303+421	92.82	8:58	94.24	15:28	295
1066	273+303+421	92.54	8:58	94.19	15:27	229
1067	284+303+421	92.87	8:57	94.10	15:32	255
1068	206+284+303+421	93.17	8:54	94.35	15:25	375

Three chosen solutions for further analysis

Scenarios 1036, 1056, and 1068 are chosen for further analysis in chapter 8.
For the first solution direction, there are six different scenarios that achieve the A1 response performance target. From these six scenarios, scenario 1036 is chosen for further analysis although it is neither the cheapest nor the highest performing solution from that solution direction. Scenario 1036 only consists of two relocations of stations (in contrast to 1037, 1038, and 1040 which need three relocations of stations) and does not include moving the larger station Emmen (as in 1034 and 1041). That is why this solution is chosen over the other solutions from that solution direction. Scenario 1056 and 1068 are chosen since they are the cheapest and best performing solutions from their solution direction that achieve the target.



6.5 Evaluation of three alternative EMS designs

This section is organised as follows:
First an overview of the three chosen EMS designs is presented (section 6.5.1). Histograms of the A1 response times are compared in section 6.5.2. The A1 response performance per municipality is compared in section 6.5.3.

6.5.1 Overview three EMS designs

An overview of the scenarios that are chosen for further analysis is presented in Table 28.

Table 28 Overview three chosen scenarios for further analysis

Solution	Scenario number	Scenario	A1%	A1 average	A2%	A2 average	Additional Yearly operation costs
		Current EMS design (model)	90.50	9:20	94.47	15:18	
1	1036	- Moving Hoogeveen to Hoogeveen Krakeel north (A37 exit 1 north) - Moving Coevorden to Dalen (N854/N34 west) - Reroute-enabled dispatching: (A1=1,A2,B1,B2=2) - Relocation strategy (08:00-23:00) Cover Emmen, Assen, Hoogeveen, Meppel, Tynaarlo, Coevorden	93.16	8:53	94.39	15:21	€ 118.000
2	1056	- Moving Hoogeveen to Hoogeveen Krakeel north (A37 exit 1 north) - Moving Klazienaveen to Nieuw Amsterdam (A37 exit 5 south) - Moving Coevorden to Dalen (N854/N34 west) - Additional capacity: solo Tynaarlo in evenings + weekend - Reroute-enabled dispatching: (A1=1,A2,B1,B2=2)	93.31	8:53	94.29	15:26	€ 120.000
3	1068	- Additional capacity: solo Tynaarlo in evenings + weekend - ALS dayshifts + 60minutes - Reroute-enabled dispatching: (A1=1,A2,B1,B2=2) - Relocation strategy (08:00 – 23:00) Cover node Emmen, node Hoogeveen, Tynaarlo	93.17	8:53	94.35	15:25	€ 375.000

From Table 28 it can be observed that solutions 1 and 2 are the cheapest solutions. However, the costs of relocating a station are not taken into account. The average A1 response times have also decreased with 27 seconds in all three solutions. The main (dis)advantages of the three types of solutions are presented in Table 29.

Table 29 Overview (dis)-advantages three solutions

	Advantages	Disadvantages
Solution 1	- Relatively cheap solution - Does not require new personnel	- May lead to a lower work satisfaction because of the many relocations - Includes moving two stations
Solution 2	- Relatively cheap solution - Vehicles do not have to relocate	- Requires additional shifts - Includes moving three stations
Solution 3	- Does not include moving stations	- Relatively expensive solution - Requires additional shifts - May lead to a lower work satisfaction because of the many relocations

The outcomes from Table 28 are the outcomes from simulating the different designs for three years. In order to create a confidence interval of the results, these three years are cut into batches of half a year. Table 30 presents the 95% confidence interval for each EMS design. Note that the average A1 response performance from Table 30 can deviate from Table 28 since the number of calls is not constant over the batches.

Table 30 Confidence interval of results

J (half a year)	Current EMS design	Solution 1	Solution 2	Solution 3
1	90.72	93.35	93.09	92.59
2	90.85	92.86	93.61	93.35
3	90.66	93.55	93.36	93.67
4	89.57	92.30	92.60	92.53
5	90.55	92.55	92.36	93.13
6	90.66	93.38	93.83	93.72
Average	90.50	93.00	93.14	93.17
Left bound Conf. Int.	90.01	92.47	92.54	92.62
Right bound Conf. Int.	90.99	93.53	93.74	93.71

Table 30 shows that for a confidence level of 95% the half width confidence interval is ±0.5% for all designs.
The paired t-test shows that all three solutions have a significant higher A1 response time performance than the current system. There were no significant differences found in the A1 response time performance between the different solutions. See Appendix K for technical details about the significance test and Appendix O for a comparison of different solutions.

6.5.2 Histogram of A1 response performance

Figures 29-31 compare the division of A1 response times for the current EMS with solutions 1, 2, and 3 respectively.

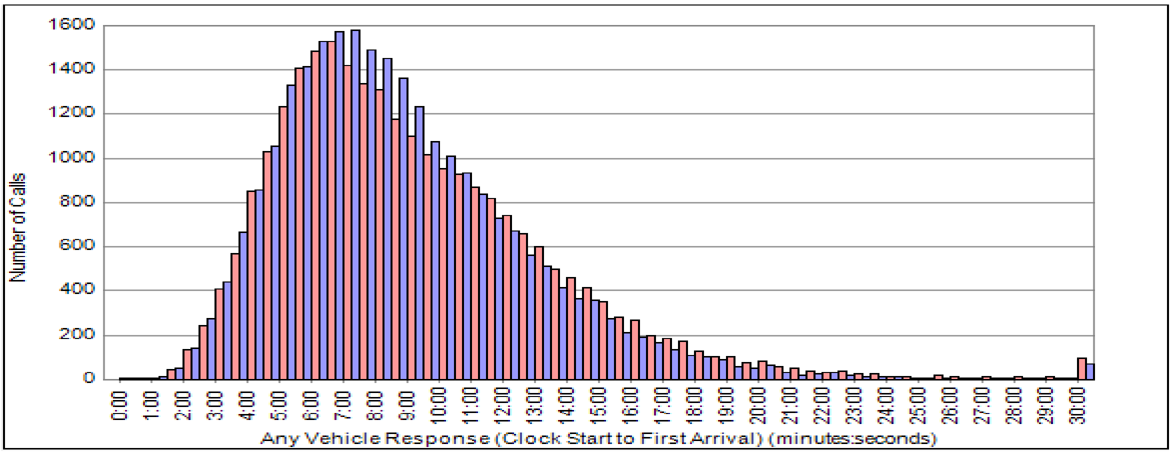


Figure 29 Histogram A1 response performance: Current EMS design (red) and solution 1 (blue)

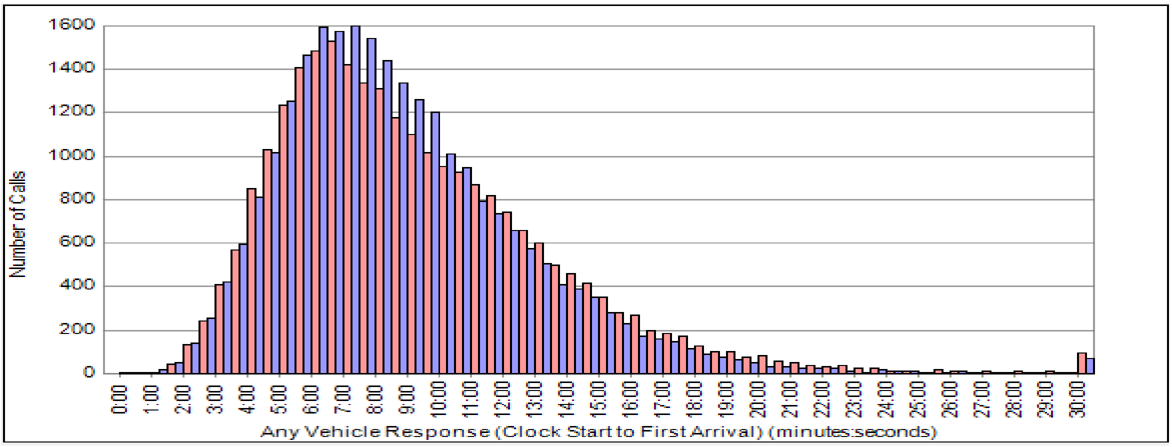


Figure 30 Histogram A1 response performance: Current EMS design (red) and solution 2 (blue)

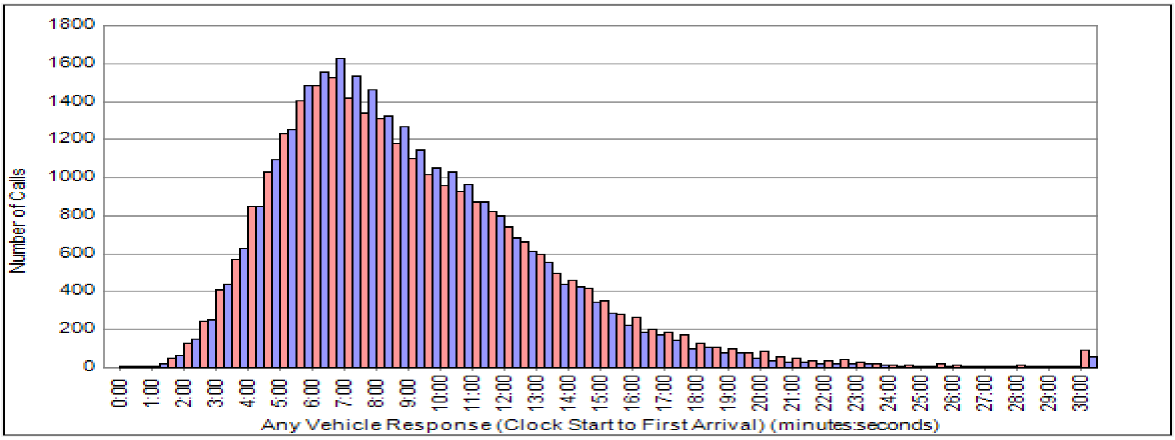


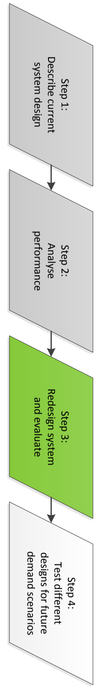
Figure 31 Histogram A1 response performance: Current EMS design (red) and solution 3 (blue)

Figures 29-31 are pretty similar. All solutions increase the number of A1 calls with a response time of less than 11 minutes and thereby decrease the number of A1 calls with a response over 11 minutes. Especially the number of A1 calls with a response time between 6 and 10 minutes increase by these solutions.

6.5.3 A1 response performance per municipality

Table 31 displays the number of A1 calls, the response performance, and number of A1 calls with a response time over 15 minutes per municipality. It also shows the contribution to the total number of calls with a response time over 15 minutes for each municipality.
The following can be observed from Table 31:

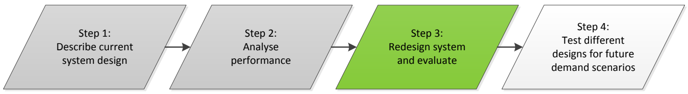
- All solutions improve the response performance in the larger cities, while some more rural municipalities have the same response performance or even worsen a bit (see the municipalities that are marked yellow and red in Table 31).
- The three municipalities that contribute the most calls with a response time over 15 minutes to the total number of calls with a response over 15 minutes are for all solutions Emmen, Borger-Odoorn, and Midden-Drenthe, while for the current EMS design it was Emmen, Hoogeveen, and Coevorden.



		Current EMS design (model)			Solution 1			Solution 2			Solution 3		
	Number of A1 deploy-ments	Perc. <= Norm	Number > Norm	Perc. of total number > Norm	Perc. <= Norm	Number > Norm	Perc. of total number > Norm	Perc. <= Norm	Number > Norm	Perc. of total number > Norm	Perc. <= Norm	Number > Norm	Perc. of total number > Norm
AA EN HUNZE	1,361	91.04%	122	5.00%	91.77%	112	6.38%	93.17%	93	5.41%	91.23%	110	6.27%
ASSEN	3,361	96.13%	130	5.33%	97.89%	71	4.04%	98.13%	63	3.67%	98.33%	56	3.19%
BORGER-ODOORN	1,149	80.16%	228	9.34%	80.68%	222	12.64%	82.42%	202	11.76%	81.90%	208	11.85%
COEVORDEN	2,086	83.41%	346	14.18%	94.58%	113	6.44%	93.53%	135	7.86%	94.01%	125	7.12%
DE WOLDEN	930	87.74%	114	4.67%	87.42%	117	6.66%	85.70%	133	7.74%	89.46%	98	5.58%
EMMEN	6,687	94.44%	372	15.25%	95.77%	283	16.12%	96.23%	250	14.55%	95.53%	299	17.04%
HOOGEVEEN	2,852	89.24%	307	12.58%	95.13%	139	7.92%	93.62%	182	10.59%	95.20%	137	7.81%
MEPPEL	1,397	88.33%	163	6.68%	94.20%	81	4.61%	90.77%	129	7.51%	90.26%	136	7.75%
MIDDEN-DRENTHE	1,749	88.51%	201	8.24%	87.94%	211	12.02%	89.37%	186	10.83%	86.79%	231	13.16%
NOORDENVELD	1,546	86.48%	209	8.57%	86.80%	204	11.62%	89.13%	168	9.78%	89.97%	155	8.83%
TYNAARLO	1,767	90.89%	161	6.60%	94.45%	98	5.58%	94.23%	102	5.94%	94.11%	104	5.93%
WESTERVELD	801	89.14%	87	3.57%	86.89%	105	5.98%	90.64%	75	4.37%	88.01%	96	5.47%
Total	**25,686**	**90.50%**	**2,440**		**93.16%**	**1,756**		**93.31%**	**1,718**		**93.17%**	**1,755**	

(green)	Total number of calls with a response time over 15 minutes has dropped compared to the current EMS design
(yellow)	Total number of calls with a response time over 15 minutes has remaind approximately the same compared to the current EMS design
(red)	Total number of calls with a response time over 15 minutes has increased compared to the current EMS design
(orange)	Municipality that is in the top 3 contributers for the total number of calls with a response time over 15 minutes

Table 31 A1 response performance per municipality for different solutions



6.6 Summary

This chapter served as the third step in the research step plan and answered the research question: "What are the possibilities for redesigning the EMS system in order to improve the A1 response performance in a cost-efficient way?"

In chapter 5 a lot of small possible causes were identified that can contribute to the number of calls with a response time over 15 minutes. For all these causes solutions were developed by altering the settings of the four logistic design parameters. Because of the complexity of the system, discrete event simulation was chosen to test different settings. There were two rounds of simulations: the first round with single changes to the system and a second round were effective and cost-efficient combinations from round 1 were combined to create a solution that met the objectives of this study. The main findings of both rounds are summarized below.

Main findings from simulation round 1:

- Moving one station can improve the A1 response performance up to 0.37% by providing better coverage for other high demand areas.
- Additional capacity is costly. Only additional solos are cost-efficient because of lower salary costs. An additional solo for a part of the day can improve the A1 response performance up to 0.25%. An additional solo in the weekends and evenings in Tynaarlo can improve the A1 response performance up to 0.44%.
- Using reroute-enabled dispatching can improve the A1 response performance by 1.28%. This is a very cost-efficient solution since it does not require any investments.
- Using a relocation strategy can improve the A1 response performance up to 0.97%. This solution requires the vehicles to drive a lot of empty kilometres resulting in higher fuel costs and may result in dissatisfied employees. In this solution, the cities gain at the costs of rural areas.

The most cost-efficient solutions improve the performance in the cities while the performance in more rural areas remains the same or decreases.

Main findings from simulation round 2:
Three main types of solutions were developed that resulted in a design that fulfilled the A1 response performance objective of this study:

1. Reroute-enabled dispatching + moving stations + relocation strategy
2. Reroute-enabled dispatching + moving stations + additional resources
3. Reroute-enabled dispatching + relocation strategy + additional resources

In total there were nine designs that met the 95% response time target of this study. From these designs, three solutions that achieved the response time target were chosen for further analysis. The additional yearly costs of these three solutions vary from €118,000 to €375,000. The first two types of solutions have lower additional yearly costs than solution 3. However, these cost calculations do not include the costs of moving stations. An overview of these three types of solutions and their main dis(advantages) can be found in Tables 28 and 29 respectively.
All three solutions have a significant higher A1 response performance and improve the A1 response performance by more than 2.5% and decrease the average A1 response time by 27 seconds compared to the current EMS design. All solutions improve the performance in the cities while the performance in the more rural areas remains the same or is slightly worse.

7. FUTURE DEMAND SCENARIOS: Effects on different EMS designs

EMS systems have developed into a vital community resource embedded in the health system. Were it was once an emergency transport system, EMS suppliers now provide a range of healthcare needs like pre-hospital emergency and primary care, emergency and non-emergency patient transport, and referrals to alternative healthcare professionals. (Lowthian et al., 2011) These developments together with an aging population places more strain on ambulance resources. Therefore it is interesting to see how the current design and the three selected designs from chapter 6 will perform for different future scenarios. This chapter is the last step from the research step plan answers the fifth research question: “What is the effect of relevant future demand scenarios on the response performance of different EMS designs?”

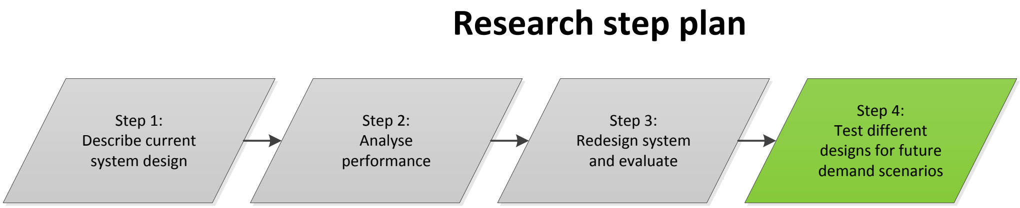


Figure 32 Research step plan: step 4

Figure 33 shows the aspects from the conceptual model that are addressed in this chapter.

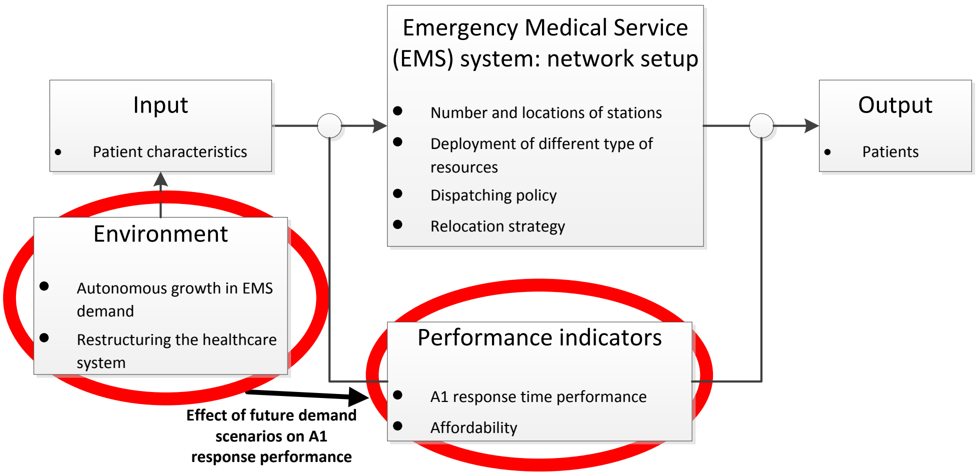


Figure 33 Conceptual model: aspects addressed in chapter 7

This chapter consists out of two major parts:

- First, relevant future scenarios are constructed. (section 7.1)
- Secondly, the current and three chosen EMS designs from step 3 are simulated and evaluated for the relevant future scenarios. (section 7.2)

7.1 Relevant future demand scenarios

In chapter one a distinction was made between:

- Autonomous growth in EMS demand
- Restructuring the healthcare system

Autonomous growth in EMS demand is addressed in section 7.1.1 while restructuring the healthcare system is addressed in 7.1.2. Both sections address the impact of these developments on demand for EMS. An overview of the future scenarios is provided in section 7.1.3.

7.1.1 Autonomous growth in EMS demand

A part of demand for EMS can be explained by the size and age of the population. (Australian Institute for Primary Care, 2007) Since the day of birth for every patient is registered, the age of every patient can be calculated. It is also known how many people per age group live in Drenthe. Combining these two types of data allows for calculating the demand per age group for different EMS in Drenthe. This is displayed in Figure 34.

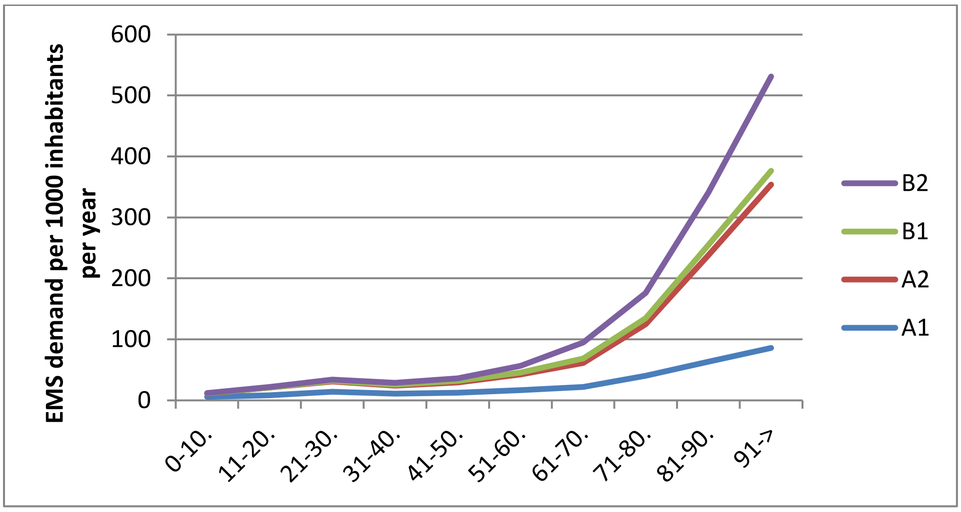


Figure 34 Demand for different EMS per 1000 people per age category in Drenthe for 2011 (Data: UMCG ambulancezorg)

From Figure 34 it is clear that older people demand more EMS per 1000 inhabitants from that age category than younger people. Since the population in Drenthe is ageing, this means that EMS demand will increase. With the aid of a population forecast for the region Drenthe, it is possible to calculate the expected EMS demand for the next years assuming the demand for different EMS per 1000 people per age category remains constant over the years. That is, there is no increase in the utilization per 1000 inhabitants per age category. This assumption is, however, too conservative. The demand per 1000 inhabitants per age category has also increased in the years 2005-2011. To incorporate this increase, the resulting demand is also calculated for an additional 2% increase in demand per 1000 inhabitants for each age category. Table 32 shows the resulting demand in numbers and as a percentage increase from 2011 for each scenario for the years 2012, 2017 and 2022. Total EMS demand for each scenario is displayed in Figure 34. Details can be found in Appendix M.

Table 32 Future EMS demand Drenthe based on population

Increase in utilization per 1000 inhabitants per age category		2011	2012		2017		2022	
			0%	2%	0%	2%	0%	2%
Resulting demand	A1	9877	10036	10237	10584	11854	11021	13446
	A2	16079	16468	16797	17761	19893	18856	23004
	B1	1929	1972	2012	2121	2376	2243	2736
	B2	7220	7450	7599	8205	9190	8853	10800
	Total	35105	35926	36645	38671	43312	40972	49986
Increase in demand from 2011 (in %)	A1	0	1.6%	3.6%	7.2%	20.0%	11.6%	36.1%
	A2	0	2.4%	4.5%	10.5%	23.7%	17.3%	43.1%
	B1	0	2.2%	4.3%	10.0%	23.2%	16.3%	41.8%
	B2	0	3.2%	5.2%	13.6%	27.3%	22.6%	49.6%
	Total	0	2.3%	4.4%	10.2%	23.4%	16.7%	42.4%

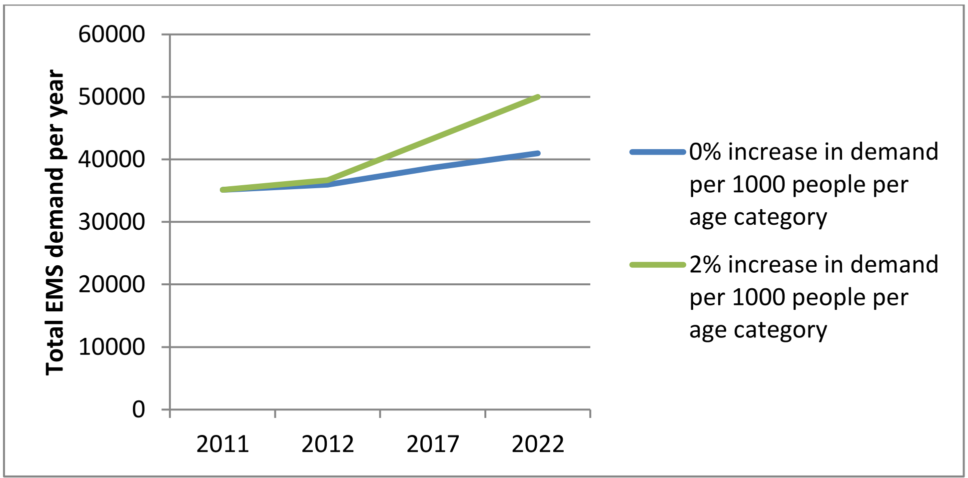


Figure 35 Total future EMS demand Drenthe

Although the total population remains fairly constant in the next ten years, it can be observed from Table 32 and Figure 35 that demand for EMS will increase based on the composition of the population. This is because older people demand more EMS. Especially the number of B2 deployments will rise.

7.1.2 Restructuring the healthcare system

According to the Health Council of the Netherlands (2012) the credo of modern accident and emergency treatment is “Close by if possible, a little further away when necessary”. Speed is still important, but there are other ways to measure the quality of the provided care. For some patients it might be better to travel to the second nearest hospital if the provided care in that hospital better matches the care needed for the patient. Accordingly, not every emergency department (ED) is required to provide all types of care. Continuing along this line of thinking one might conclude that it is not necessary for all EDs to be open 24 hours a day. Closing down an ED may reduce the availability of vehicles to other calls in two ways:

- Longer driving times to nearest ED
- Possibly longer hand-over times at the hospital because of overcrowding

Recall from chapter 2 that there is also a 45 minutes norm that states that patients should be able to reach a hospital within 45 minutes from the moment the call is received. One can imagine that closing down emergency departments is likely to affect this 45 minutes norm. However, the focus in this research is on the A1 response time performance and therefore we will not look at the effects of closing down emergency departments on this 45 minutes norm.

In Denmark, they have already gone through some reorganisations based on an advice from the Danish Health Council. The advice was to have approximately one ED per 200.000 - 400.000 inhabitants. This advice will be used as a guideline to create different scenarios. This advice is appropriate because the geographic characteristics of the main island Jutland are pretty similar to the Netherlands. Table 33 provides an overview of the number of inhabitants in the three Northern provinces of the Netherlands.

In total there are 1,717,000 inhabitants in the three Northern provinces. Following the Danish guideline this roughly leads to between 4 and 9 EDs in the three Northern provinces. Currently there are 15 EDs including two hospitals in Overijssel. These hospitals in Overijssel are included since they are relevant for the EMS system in Drenthe. Table 34 provides an overview of the constructed different ED scenarios. An overview of the locations of all hospitals can be found in Appendix F.

Table 33 Inhabitants Northern Netherlands

Province	Inhabitants (x1000)
Groningen	579
Friesland	647
Drenthe	491
Total	**1,717**

Table 34 Overview ED scenarios

	Hospital	Currently	Scenario A	Scenario B	Scenario C
Groningen	UMCG	7X24	7X24	7X24	7x24
	Martini ziekenhuis Groningen	7X24	7X24	7X24	7X24
	Refaja ziekenhuis Stadskanaal	7x24	Closed	Closed	Closed
	Delfzicht ziekenhuis Delfzijl	7x (07.00 – 19.00)	Closed	Closed	Closed
	St. Lucas ziekenhuis Winschoten	7x24	7x24	7x (07.00 – 19.00)	Closed
Friesland	Nij Smellinghe Drachten	7x24	Closed	Closed	Closed
	De Tjongerschans Heerenveen	7x24	7X24	7x (07.00 – 19.00)	Closed
	Antonius Ziekenhuis Sneek	7x24	7x24	7x (07.00 – 19.00)	Closed
	Medisch Centrum Leeuwarden	7x24	7x24	7x24	7x24
Drenthe	Wilhelmina ziekenhuis Assen	7x24	7x24	7x (07.00 – 19.00)	Closed
	Diaconessen ziekenhuis Meppel	7x24	Closed	Closed	Closed
	Scheper ziekenhuis Emmen	7x24	7x24	7x24	7x24
	Bethesda ziekenhuis Hoogeveen	7x24	7x24	7x (07.00 – 19.00)	Closed
Overijssel	Isala Klinieken Zwolle	7x24	7x24	7x24	7x24
	Saxenburgh Groep Hardenberg	7x24	Closed	Closed	Closed

7.1.3 Overview future demand scenarios

Two types of scenarios are created: 1) increasing demand for different EMS services based on a population forecast, and 2) closing different emergency departments.

Combining the future EMS demand scenarios with closing down emergency departments leads to (4x7=) 28 combinations. These scenarios will be used to test the current system design and three possible redesigns of section 6.4. Table 35 provides an overview of what each scenario entails. For a complete explanation of the scenarios see Tables 32 and 34.

Table 35 Overview future scenarios

Variable 1	Current ED scenario	0 hospitals closed
(ED scenarios)	Scenario A	5 hospitals closed
	Scenario B	5 hospitals closed, and 5 partly closed
	Scenario C	10 hospitals closed
Variable 2	2011	Baseline demand
(EMS demand	2012(0)	Increase total EMS demand by 2.3% from 2011
scenarios)	2012(2)	Increase total EMS demand by 4.4% from 2011
	2017(0)	Increase total EMS demand by 10.2% from 2011
	2017(2)	Increase total EMS demand by 23.4% from 2011
	2022(0)	Increase total EMS demand by 16.7% from 2011
	2022(2)	Increase total EMS demand by 42.4% from 2011

7.2 Response performance for different designs for future demand scenarios

This section analyses how the current and the three chosen designs of section 6.4 perform for different future demand scenarios. By using discrete event simulation these future scenarios were modelled and simulated. Figures 36-39 show the resulting A1 response performance for the different future scenarios. The resulting demand for scenario 2022(0) is lower than for scenario 2017(2). This leads to an increase in the A1 response performance and explains the peak for 2022(0) in Figures 36-39.

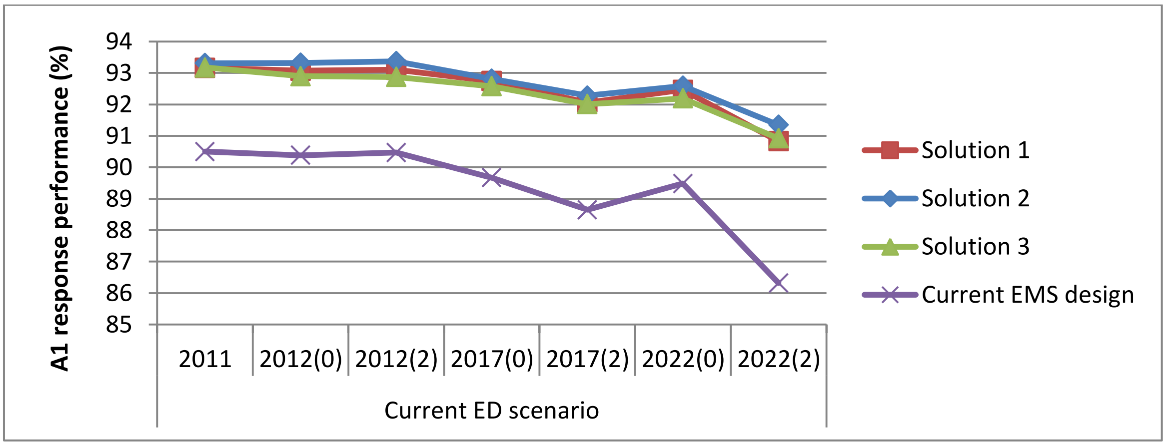


Figure 36 A1 response performance: Current ED scenario

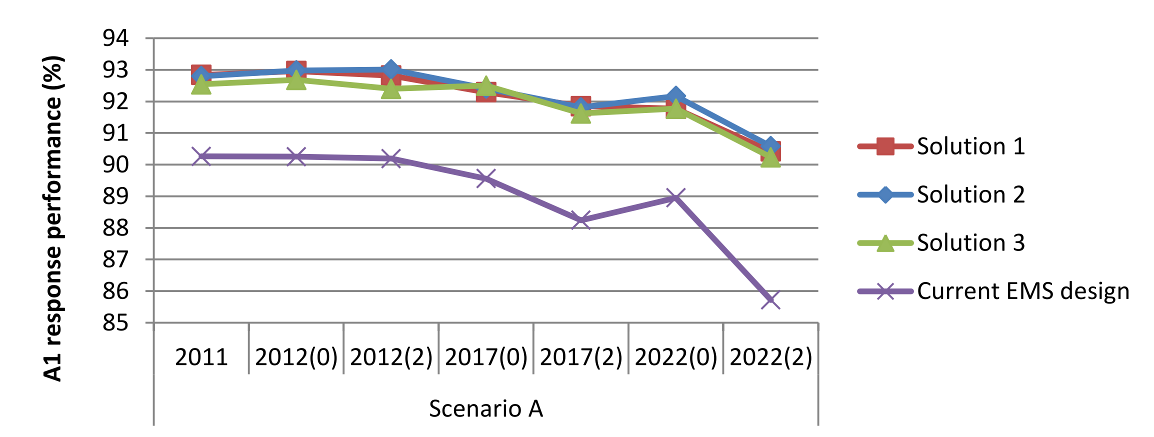


Figure 37 A1 response performance: Scenario A

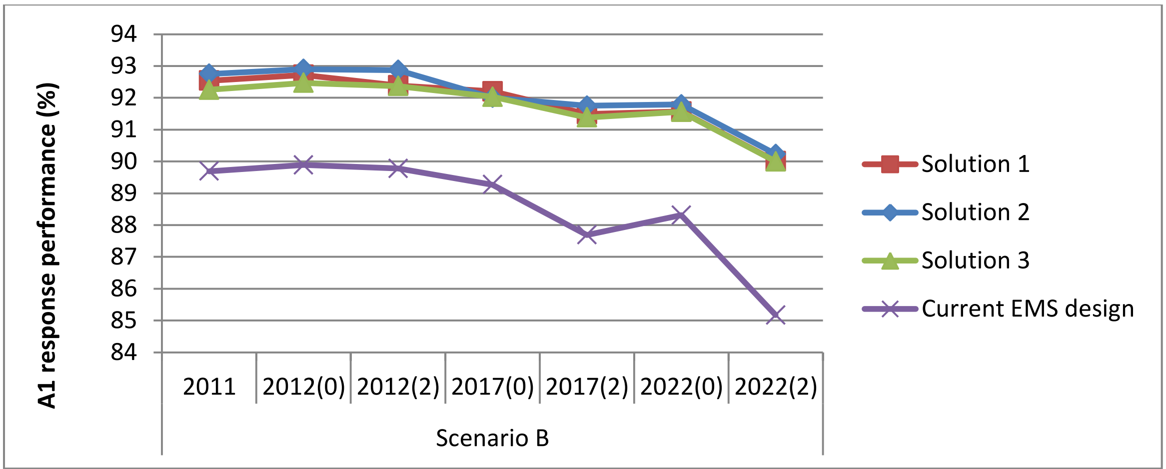


Figure 38 A1 response performance: Scenario B

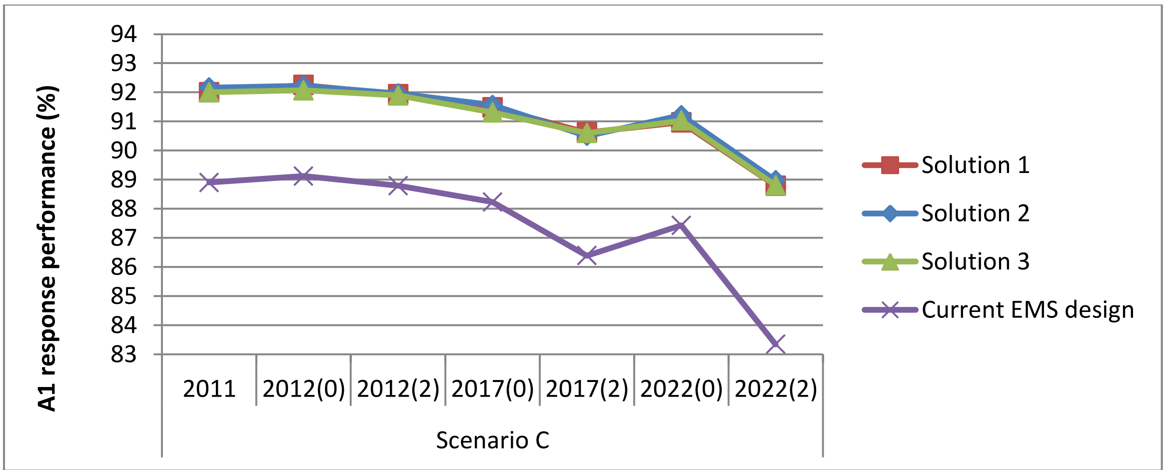


Figure 39 A1 response performance: Scenario C

From Figures 36-39 we can observe the following:

- There are remarkably little differences in the A1 response performance for the different designs for different future scenarios. In general, solution 2 seems to perform a little bit better than the other two solutions. However, the differences are two small to be significant. (see Appendix O)
- The A1 response performance of all three designs remains the same or even increases a bit for a small increase in demand (scenarios 2012(0) and 2012(2)), while

the A1 response performance decreases for a stronger growth in demand. See section 8.2.1.

- The A1 response performance decrease when more hospitals are closed, that is performance current scenario > performance scenario A > performance scenario B > performance scenario C. This is true for all three solutions and the current EMS design. See section 8.2.2.

7.2.1 A1 response performance for different EMS demand scenarios

Figure 40 displays the average difference in A1 performance compared to the performance for the current demand level. The numbers are averaged over different ED scenarios.

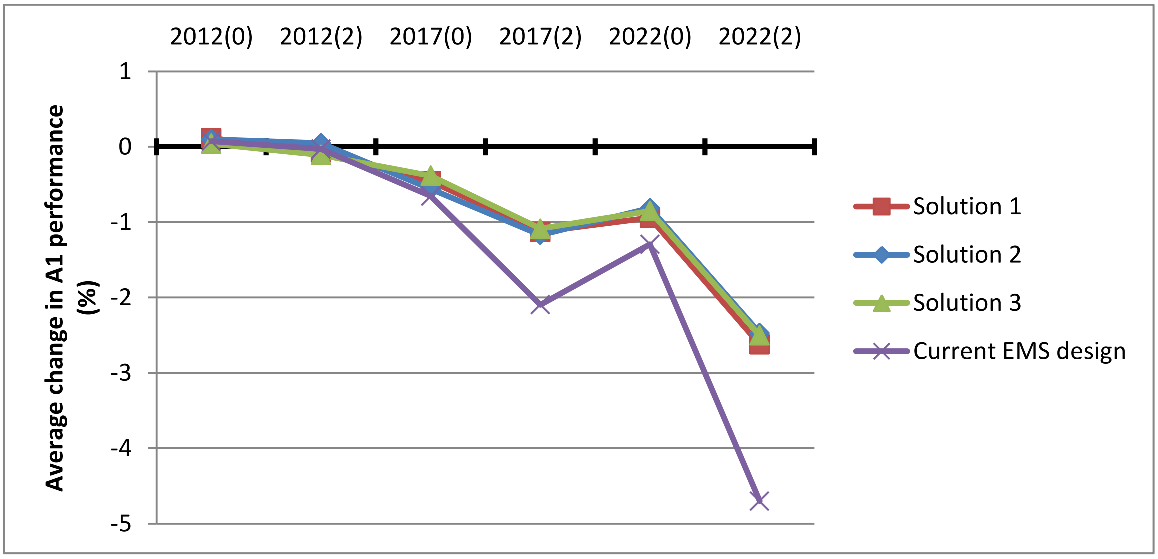


Figure 40 Average change in A1 performance for EMS demand scenarios

From Figure 40 it can be observed that the three solutions tend to decrease less in the A1 response performance for different EMS demand scenarios than the current EMS design. It was found that on average for different ED scenarios the response performance:

- increases by 0.0% - 0.1% for demand scenario 2012(0);
- decreases by 0.0% - 0.1% for demand scenario 2012(2);
- decreases by 0.4% - 0.6% for demand scenario 2017(0);
- decreases by 1.1% - 1.2% for demand scenario 2017(2);
- decreases by 0.8% - 0.9% for demand scenario 2022(0);
- decreases by 2.5% - 2.6% for demand scenario 2022(2).

The range in the above outcomes is the difference between the smallest and the largest drop in the A1 response performance for the three designed solutions.

7.2.2 A1 response performance for different ED scenarios

Figure 41 displays the average decrease in A1 response performance for different ED scenarios compared to the current ED scenario. The numbers are averaged over different EMS demand scenarios.

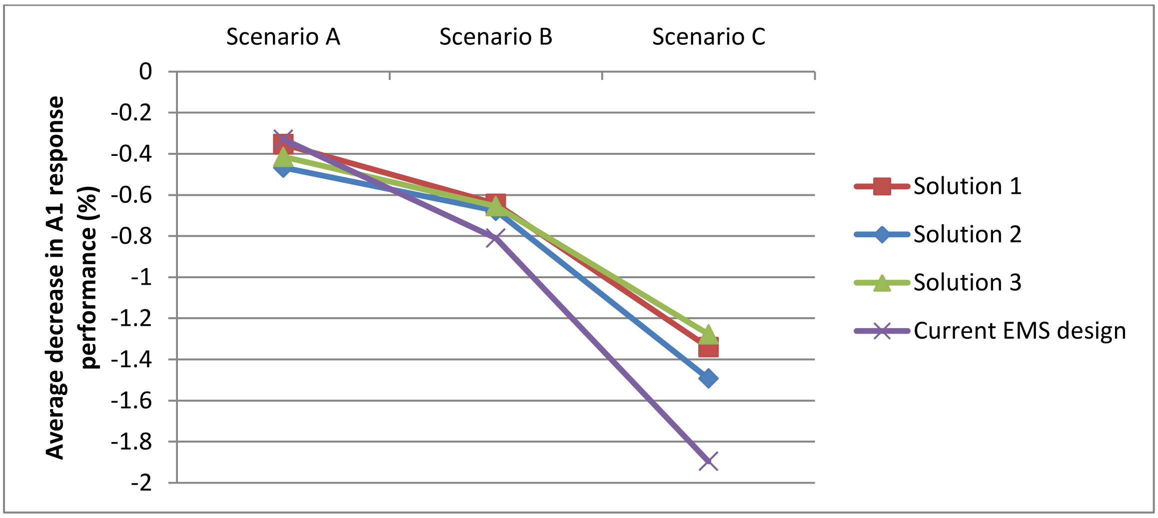


Figure 41 Average decrease in A1 response performance for ED scenarios

From Figure 41 it can be observed that the three solutions tend to decrease less in the A1 response performance for scenarios B and C than the current EMS design. It was found that on average for different demand scenarios the response performance:

- decreases by 0.4% - 0.5% for scenarios A, which is closing down 5 EDs;
- decreases by 0.6% - 0.7% for scenario B, which is closing 5 EDs, and closing 5 EDs at night;
- decreases by 1.3% -1.5% for scenario C, which is closing 10 EDs.

The range in the above outcomes is the difference between the smallest and the largest drop in the A1 response performance for the three designed solutions.

7.3 Summary

In this chapter the three chosen solutions from chapter 6 and the current EMS design were tested for different future demand scenarios. This chapter was thereby the last step of the research step plan and answered the research question: “What is the effect of relevant future demand scenarios on the response performance of different EMS designs?”

It was found that all three solutions react similarly to different future scenarios in terms of A1 response performance. In general, all three solutions could better cope with an increase in demand or closing down hospitals than the current EMS design.

An increase in demand of more than 10% negatively affects the A1 response performance for all three solutions between 0.4% (10.2% growth in total EMS demand) and 2.6% (42.4% growth in total EMS demand). For the current EMS system this was between 0.7% and 4.7% respectively.

Closing down emergency departments negatively affects the A1 response performance for all three solutions between 0.4% (closing down 5 emergency departments) and 1.5% (closing down 10 emergency departments). For the current EMS system this was between 0.3% and 1.9% respectively.

All three solutions will be able to achieve the A1 response performance target for a few years. Additional measure should be taken before 2017. Since demand was calculated for 2012, 2017, and 2022 it cannot be stated in which year the A1 response performance will drop below the 95% again. However, it will be somewhere between 2012 and 2017. Closing down emergency departments will advance this moment.

8. CONCLUSIONS AND RECOMMENDATIONS

The A1 response performance in the Dutch region Drenthe is below the required 95%. This means that the local EMS supplier, UMCG ambulancezorg, is not able to reach the scene within 15 minutes for 95% of the most urgent A1 calls. Since this is desired by neither the patient nor UMCG ambulancezorg, the objective in this research is to improve the A1 response time performance. The central research question in this project is therefore:

In what way can the response performance of A1 emergency calls be improved by redesigning the EMS system for the current and possible future scenarios?

With the aid of literature there were four design parameters identified in this research: location and number of stations, EMS resource schedule, dispatching policies, and relocation strategy. It was found that the interpretation of these four design parameters largely determines the A1 response performance. These four design parameters also play a central role in the research step plan as defined in this research. This research step plan consist of the following four steps: 1) describing the current system, 2) analysing the current performance, 3) redesigning the system and evaluation, and 4) testing different designs for relevant future demand scenarios.

The main research question is answered based on the most important findings of the research step plan in section 8.1 Recommendations are discussed in section 8.2, while limitations and suggestions for further research are addressed in section 8.3.

8.1 Conclusion

In this section the main findings from the research step plan are presented, that is the main findings from the performance analysis, the redesign and the robustness test of different EMS designs for relevant future demand scenarios.

The performance analysis resulted in the following observations. The response performance in percentages is relatively higher in the cities while significantly lower in more rural areas. However, looking at the absolute number of calls with a response time over 15 minutes, it was found that there were no time segments or locations that perform exceptionally worse than other time segments or locations. In general, most of the calls with a response time over 15 minutes are concentrated in the cities, the rural area between Hoogeveen and Emmen, and the North of Drenthe. The response performance at daytime is higher than at night. However, due to the large number of calls at daytime there is still the most room for improvement at daytime. Besides these general observations, there was found to be a small dip in the A1 performance between 17:00 and 18:00.

The above observations can be explained by the following reasoning. A feasibility test shows that ambulances are not able to reach a large rural part in the centre of Drenthe within 12 minutes driving time. This largely explains the low A1 response performance in the centre of Drenthe. Except for this rural area, the location of calls with a response time over 15 minutes are often well within the reach of the nearest base. The main reason for calls to have a response time over 15 minutes can be attributed to not having a vehicle available at the nearest base. Although a large part of Drenthe is statically covered by an ambulance, that is, almost every place can be reached within a 12 minutes driving time from the nearest base, the actual coverage is far less because ambulances are busy serving other calls. Since most areas are covered by just one or two ambulances, there are situations where an ambulance from another working area has to serve an A1 call outside her normal working area. This

often results in a call with a response time over 15 minutes. Especially areas with high arrival rates are vulnerable for these situations. Therefore solutions that can improve the availability of vehicles at high demand locations are likely to improve the A1 response time performance. The dip in the performance between 17:00 and 18:00 can be explained by ending dayshifts at 17:00.
The following trade-off is apparent: the trade-off between the performance in the rural and non-rural areas. As consonant with literature, high efficiency gains can be obtained by focussing on high risk or non-rural areas where most of the calls for assistance occur. This focussing on high risk areas comes at the costs of performance losses in smaller towns or rural areas where calls are less likely to occur. Since additional personnel are expensive, the cities should receive the main priority for improvement because of their large impact on the total response performance in Drenthe.

Redesign and evaluation
Based on the findings from the performance analysis a number of possible solutions were constructed by altering the setting of the four design parameters. By means of discrete event simulation these solutions were tested for their effect on the A1 response performance. The main findings are:

- Location and number of stations: Moving a station near a highway in order to provide coverage for the working area of another station can improve the A1 response performance up to 0.44%. Especially Coevorden, Emmen and the rural area around Hoogeveen can improve by providing better coverage by moving stations. Since moving a station does in general not increase the yearly operational costs, it is cost-efficient to relocate stations.
- EMS resource schedule: An additional solo on weekdays (08:00-17:00), weekdays (17:00-23:00) or weekends (09:00-18:00) can improve the A1 response performance up to 0.25%. An additional solo is more cost-efficient than an ALS vehicle because of fewer personnel costs. Especially a solo in Tynaarlo or Emmen in the weekends and evenings can help to improve the A1 response performance. However because of personnel costs, additional resources in general are less cost-efficient than the other solutions mentioned here.
- Dispatching policies: Consistently using reroute-enabled dispatching can improve the response performance up to 1.28% and has little effect on the lower priority calls. Reroute-enabled dispatching is always reassigning an ALS ambulance to a call when it was on his way to a lower priority call and it is the nearest vehicle.
- Relocation strategy: Using a relocation strategy to cover the larger places from 08:00-23:00 can improve the A1 response time by 0.97%. However, it causes many ambulances to be on the road which might not be preferred by employees and raises the fuel costs.

In general, in order to improve the A1 response time performance, it is very important to cover the areas where the probability of an A1 deployment is the highest. This is true, because these areas are most likely to create calls that exceed the response time norm. A cost-efficient way to do this is either by moving stations to provide multiple coverage for high demand areas or using a relocation strategy. The downside of this cost-efficient approach is that the A1 response performance in the more rural areas will decline. This is the trade-off between rural and non-rural areas.

Combining different solution concepts yielded three types of combinations that achieved the response performance target of this research:

1. Moving stations + reroute-enabled dispatching + relocation strategy
2. Moving stations + additional capacity + reroute-enabled dispatching
3. Additional capacity + reroute-enabled dispatching + relocation strategy

All three types of solutions resulted in a design that is able to meet the A1 response performance objective. These solutions have a significantly higher A1 response performance and improve the current A1 response performance by more than 2.5%. Furthermore, these solutions also improve the average A1 response time by 27 seconds. A solution of type 1 or 2 is more cost-efficient than solution type 3.

All three types of solutions and the current EMS design were tested for the impact of increasing EMS demand and closing down emergency departments on the A1 response performance. The A1 response performance for all three solutions was found to be very similar for different future demand scenarios. A small growth in demand for the year 2012 (2-4%) has almost no effect on the A1 response performance. This is not strange, since the utilization of different vehicles remains low. For larger growth in EMS demand, the A1 response performance decreases between 0.4% and 1.2% for the year 2017 and decreases between 0.8% and 2.6% for the year 2022.
Closing down emergency departments negatively affects the A1 response performance for all three solutions between 0.4% (closing down 5 EDs) and 1.5% (closing down 10 EDs). For all three solutions the drop in A1 response performance was less than for the current EMS design under different future scenarios. Therefore these three solutions are more robust than the current EMS system.

8.2 Recommendations

This section presents the main recommendations based on this research. A division is made between short-term and long-term recommendations..

Short-term recommendations

For the current demand level my recommendation is to implement solution 1 or 2 since these solutions are cheaper than solution 3.

Solution 1:

1. Consistently use reroute-enabled dispatching, that is, always reassign an ALS vehicle to an A1 call when it was on his way to a lower priority call and it is the closest unit.
2. Move stations to highways in order to provide coverage for areas with high arrival rates.
    a. Move base Hoogeveen to Hoogeveen Krakeel north (A37 exit 1 north)
    b. Move base Coevorden to Dalen (N854/N34 west)
3. Use a relocation strategy to cover Emmen, Assen, Hoogeveen, Meppel, Tynaarlo, and Coevorden between 08:00 and 23:00 in that order.

Solution 2:

Consists of points 1 and 2 from solution 1, and in addition:

3. Move base Klazienaveen to Nieuw Amsterdam (A37 exit 5 south)
4. Place additional capacity in Tynaarlo in the evenings and weekends. A solo is preferred because a solo is more cost-efficient than an ALS vehicle.

The additional yearly costs of both solutions are around €120.000. This consists of personnel costs and the costs of additional kilometres by the relocation strategy. This costs calculation does not include the costs of finding a new location for the bases.

Long-term recommendations:
For the long-term, additional capacity will be required to achieve the A1 response time performance of 95%. None of the designed solutions achieves the target for an increase in total demand of more than 10% or for closing down emergency departments. Therefore, neither of these solutions will achieve the response performance target in the year 2017. Further research is required to create cost-efficient solutions that will obtain the response time performance target in the future. The findings in this research can be used as starting point. The research step plan of this research can be used to construct those solutions because it forces the researcher to investigate the underlying causes for a certain performance.

8.3 Limitations and suggestions for further research

This section discusses a few limitations and a number of suggestions for further research.

- Dataset
  The dataset used in the simulation model is historic data for only ten months. More reliable results can be obtained when a longer data period is available. It will be interesting to test the solutions developed in this research on new data.
- Single long run
  With the current simulation model it was not possible to change seed values in order to create multiple datasets. By changing the seed values of the sampling process, multiple dataset can be generated. In this way a solution can be tested for multiple runs which leads to more reliable results.
- Simulation model
  The model itself is an approximation of the real system. Since it was a first model there is always room for improvement to obtain more accurate results.
- A1 response performance versus average response time
  For this research it was the objective to achieve a specified A1 response performance target. However, optimizing the A1 response performance can negatively affect the average response time. Consider a situation where there is only one ambulance available for two places; place A and B, which are separated by a certain distance that makes it impossible to reach A from B within a certain response time limit. Place A has 90% of the calls, while place B has only 10% of the calls. If the objective is to reach a certain response time performance in percentages, it might be wise to place the ambulance somewhere in the middle of A and B so it can reach both places in time. However, the average response time would probably be lower if the ambulance was located in A.
  Further research is required in order to design an EMS system that improves upon average response times while maintaining a specified A1 response performance target.
- Other regions
  This research has only focused on Drenthe. Therefore the results are specific. This is a limitation when more general conclusions should be drawn. Drenthe is compared to

other regions in the Netherlands a relatively low population density area with relatively little traffic and traffic jams. However, the approach taken in this research is generic and it will be interesting to test the step plan and solution concepts of this research on other regions to see if similar results can be achieved.

- Municipality based growth rate
  In this research the future demand is calculated based on changes in the total population of Drenthe. However, in reality some municipalities will grow and others will shrink in the near future. This is likely to affect the real future demand. Further research is required to assess the impact of these effects.
- Interregional effects
  The simulation model that was used in this research only contained the region Drenthe. In reality EMS suppliers from surrounding regions can operate inside Drenthe and vice versa. This is likely to affect the real achieved performance, especially close to the borders from the provinces.
- Future system design
  The A1 response performance deteriorated for a substantial increase in demand and closing down emergency departments. Further research is required to determine cost-efficient solutions in these cases.
- Prior delay time
  A response time consists out of three time segments for an ambulance departing from her station: the activation input; the mobilisation duration and the travel to scene time. This research has focused on improving the latter time segment. However, this does not mean that the two other time segments should be taken for granted. In order to continuously improve the total process, these time segments should be under constant scrutiny. More research is needed to assess the impact of these time segments and to determine possibilities to improve upon them.

9. REFLECTION

Van Aken et al. (2007) stress that evaluations can be performed with four objectives in mind:

1. Evaluations serve the current business problem solving project by determining the results achieved and the improvements made
2. Evaluation may be oriented at learning for future problems
3. Evaluation and reflection can be oriented at advancing scientific knowledge about business processes
4. Evaluation and reflection are necessary for personal and professional development.

Since design has been chosen as the goal of this research it is not possible to evaluate the effects of the solution or redesign in the real world since the design has not been implemented yet. However, the other three objectives of evaluation are addressed in sections 9.1-9.3. The quality of the research is addressed in section 9.4.

9.1 Learning for future problems

There are three major objects of learning: the object design, the realization design and the process design. The realization design is not part of this research, the other two objects of learning are addressed below.

The region Drenthe is one of the 25 safety regions in the Netherlands. Other EMS systems face similar problems and can benefit from this research in two ways:

- Particular solutions can be applied to their own EMS system
- The research step plan can be applied to their own EMS system

It is expected that similar gains can be achieved by implementing similar solutions by using the research step plan defined in this research. This research step plan ensured a through analysis of the problems and an efficient way to create alternative solutions.
In total there were 478.331 A1 deployments in the Netherlands in 2011 (Ambulances in-zicht, 2011). Improving the national A1 response performance by 1% enables almost 5000 more patients in potential life-threatening situations to be reached within a 15 minutes response time.
According to some calculation of Statistics Netherlands (CBS) 90 billion was spent on the total healthcare industry in the Netherlands. This amount increases every year with a higher amount than the gross domestic product (GDP). Operations research and simulation models can help to develop cost-efficient solutions for all type of problems in this industry. This research can be another step in creating such solutions.

9.2 Scientific reflection

Reflection on a single case can contribute in four ways to the existing literature: as innovation, elaboration, verification and falsification. (Van Aken et al., 2007) How this research contributes to the existing literature is addressed below.
There were no radical innovative solutions developed in this research. All solutions are elaborations of existing designs and theories. However, the research step plan used to structure the research and analysing the response performance, developing solutions with the aid of literature and using discrete event simulation to test solutions can be regarded as innovative since it has not been performed before in the emergency medical services world.

This structured method can be applied for other EMS systems in order to improve the response performance of urgent calls.
Although the designed solutions have not been implemented yet, the claims of two particular solutions can be verified by the use of the simulation model: using reroute-enabled dispatching, and using a relocation strategy. It was stressed in literature that using these concepts would improve the response time performance for the most urgent calls. It was found that these solutions can indeed improve the response time performance of the most urgent calls by 1.09% – 1.28% for reroute-enabled dispatching and up to 1% for the relocation strategy.

9.3 Personal and professional development

I myself have also learned of this research. Writing this thesis is my last piece of work towards graduating the master Industrial Engineering & Management in Groningen. After four and a half years of taking courses it was interesting to be at a real company working on a real project.
What I have learned to be important is setting up the right structure for your report. I have rewritten and shuffled sections many times before reaching this final order. A good structure to begin with might have mitigated this problem.
Another thing that I have learned is that there is often not a single best solution. Management time, and in this case my time, is scarce. A cost-efficient solution does not only mean that the final solution is cost-efficient in terms of money. It also means creating satisfying solutions rather than optimal solutions in the scarce time that is available for projects.

9.4 Quality of the research

In this section research-oriented criteria will be addressed to assess the quality of the research. This assessment will be based on the three major criteria controllability, reliability and validity.

Controllability: The data used in this research is mainly data from a database called Dundas. Anyone with access to the database will be able to retrieve the same information. Reading through the chapter and following the research step plan provides a detailed description of how this research was conducted. Therefore, other will be able to replicate it making this research controllable.

Reliability: The results of a study are reliable when they are independent of the particular characteristics of that study and can therefore be replicated in other studies. (Van Aken et al., 2007) No EMS system is exactly the same, since this research consists of only one case; one cannot argue that this research is reliable in that sense.
In order to increase the reliability of the results from the discrete event simulation tool, each scenario had a run-length of three years. See section 8.3 for suggestions to improve the reliability.

Validity: The simulation model used in this research was validated. The model slightly underestimated the real achieved response performance, however this underestimation was structural. Therefore, the results of this study can be well justified and there are no reasons to believe why the outcomes of this research would not be true.

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APPENDICES

A. Organogram
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A. Organogram

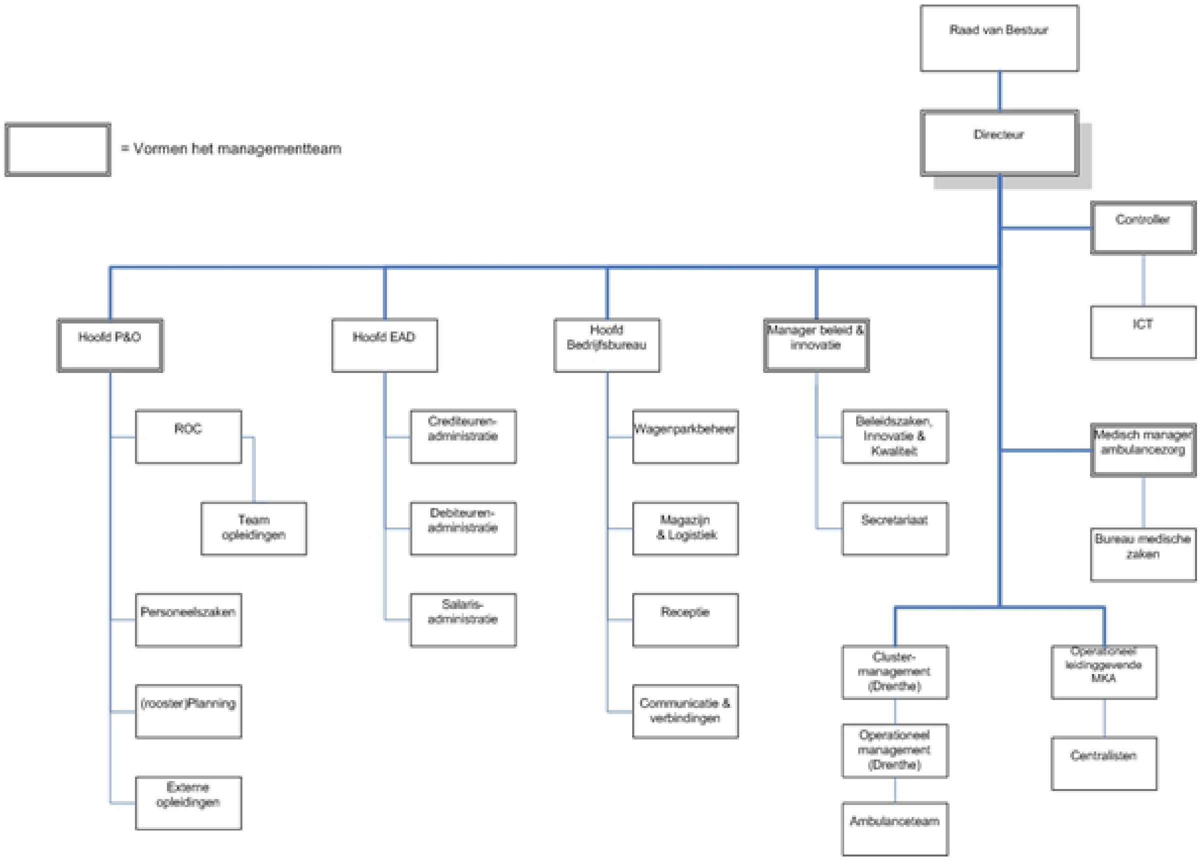

Figure A.1 Organogram UMCG ambulancezorg (In Dutch)

B. Problem analysis

Validation and diagnosis of the A1 response performance problem

This problem analysis provides a first exploration of the problem as described in chapter 2. The problem is analysed based on empirical data from the ambulance service system in the Netherlands. The second section contains a first diagnosis of possible causes of the problem. The final section concludes with a discussion and validation of the business problem.

B.1. Empirical analysis

Fortunately, the world of emergency medical services is a data rich environment. All kind of details about all different deployments are logged into an electronic database. This data is invaluable in analysing the system and will here be used to validate the business problem.

International comparison

Countries are very different from one another (i.e. geography, distances, climate, and culture), furthermore the provided ambulance services are not the same. Like described in the literature review, the performance targets may also differ. For example, in England 74.9 % of the category A incidents resulted in an emergency response arriving at the scene of the incident within 8 minutes. (The NHS Information Centre, Workforce and Facilities, 2011) Since it is hard to compare the response time performance for different countries, the focus here will be solely on the Netherlands.

National comparison

Ambulancezorg Nederland provides a yearly sector report 'Ambulance in-zicht' with data coming from all the different regions in the Netherlands.

Table B.1 presents the total A1 response performance and average time intervals for the last couple of years for Drenthe and the Netherlands.

Table B.1 Response performance A1 Drenthe (AZN, 2011)

	2011		2010		2009	
	D	NL	D	NL	D	NL
Activation Input	1:27 min	1:52 min	1:27 min	1:51 min	1:24 min	1:52 min
Mobilization Duration	0:46 min	1:02 min	0:44 min	1:02 min	0:43 min	1:09 min
Travel to Scene	6:48 min	6:36 min	6:53 min	6:45 min	6:44 min	6:42 min
Vehicle Response	9:05 min	9:32 min	9:08 min	9:40 min	8:54 min	9:44 min
< 15 minutes	93.7 %	93.3%	91.8 %	92.3%	93.4 %	92.0%

From Table B.1 it can be observed that Drenthe is actually doing quite well on the different time segments of the response time compared to the Dutch average. Only the average travel to scene time seems to be above the Dutch average. The response performance is still below the 95% target.

Region Drenthe

Using historic data from a large part of the year 2010, the A1 performance can be analysed for different areas in the region Drenthe.

<u>Figure B.1</u>: A1 response performance in Drenthe. The colour shows the specific performance A1 response performance. Green is above 95%, while red is below 85% and orange is somewhere between these values.

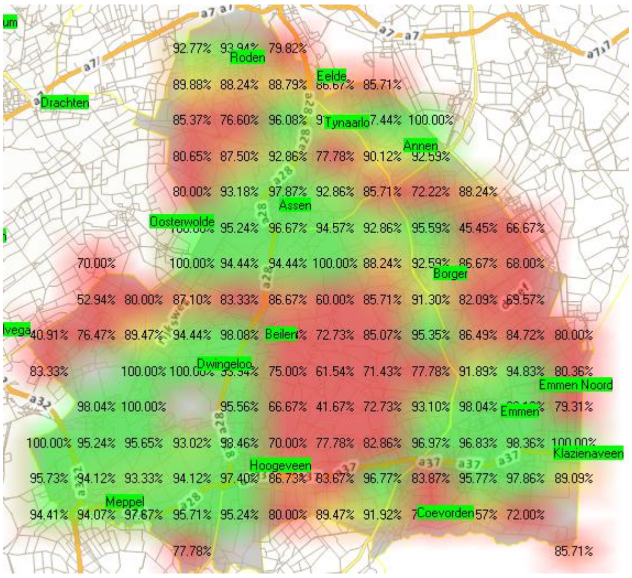

Figure B.1 Response performance of A1-priority calls in the region Drenthe. Data: 01-01-2010 – 19-10-2010

From this figure it is clear that the performance is the best around the ambulance stations and high ways.

The specific locations and number of A1 calls with a response time over 15 minutes are displayed in Figure B.2. From these figures it can be observed that the A1 calls with a response time over 15 minutes were pretty dispersed throughout the region with emphasis on the South-east of Drenthe.

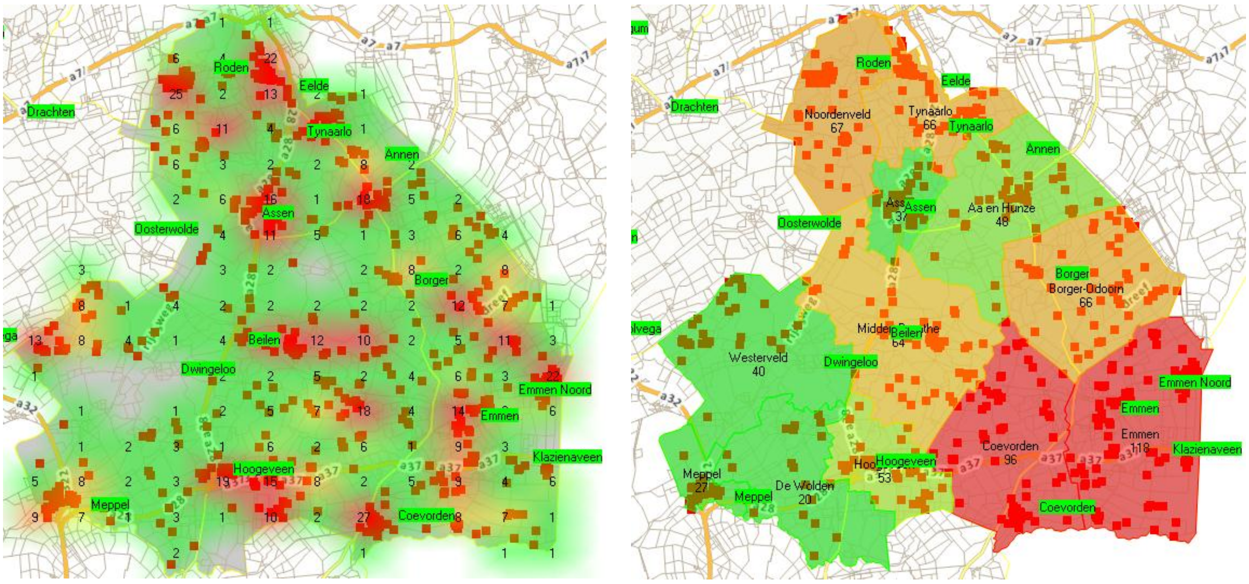

Figure B.2 Amount of A1 calls > 15 min response time (Data 01-01-2010 – 19-10-2010)
Left: Grid: 100x100; below 5 is green, above 10 is red, everything in between changes from green to red
Right: Municipalities; below 40 is green, above 80 is red, everything in between changes from green to red

B.2 Diagnosis: The direct causes of not achieving the 15 minutes response time target

For every A1-priority call the causes of not achieving the total response time of 15 minutes are registered. The response time can be divided into three different time segments for ambulances idle at their post. Note that an exceedance of the 15 minutes target can be caused by an exceedance of multiple time intervals. An exceedance of one of the three time segments does not necessarily lead to an exceedance of the 15 minutes target. The different reasons for exceeding the target are displayed in Table B.2

Table B.2 Causes of exceedance per time interval (Dundas, 2011)

		Number of deployments	Percentage of total exceedances differentiated by time fragment
Exceedances of the standard		4866	
Exceedance of the Activation Input (Received to Dispatch) > 2 minutes	**Complex call (explanation)**	66	21.36%
	No Ambu available	26	8.41%
	No Dispatch Time	12	3.88%
	Not linked	6	1.94%
	Miscellaneous (explanation)	203	65.70%
	Consultation with colleagues, management, MMA	1	0.32%
	Technical problems	24	7.77%
	Dispatch to different operating room	2	0.65%
	Total	309	100.00%
Exceedance Mobilisation Duration (Dispatch to Mobilised) > 1 minute (At daytime) > 2 minutes (At night)	**Ambulance nog yet linked**	179	19.23%
	Busy with last ride	105	11.28%
	Logistics of the post	310	33.30%
	Miscellaneous (explanation)	379	40.71%
	Plotting incorrect	282	30.29%
	Pagers malfunction	23	2.47%
	Total	931	100.00%
Exceedance of the Travel to Scene (Mobilised to Arrival) > 11 minutes > 12 minutes > 13 minutes Depends on day/night and on the road/idle at station.	**Address is not found**	76	9.77%
	Outside own working area	396	50.90%
	Outside RAV area	11	1.41%
	Traffic jam / obstacles	28	3.60%
	Breakdown ambulance	2	0.26%
	Plotting incorrect	133	17.10%
	Distance to long	216	27.76%
	Weather conditions	60	7.71%
	Road conditions	37	4.76%
	Total	778	100.00%
Total		4866	

As can be observed from the total exceedances per time interval, most of the A1 calls with a response time over 15 minutes exceeded the mobilisation duration and the travel to scene time.

From Exceedance of the Activation Input (Received to Dispatch)
A very large part of the exceedances is caused by miscellaneous reasons, so the causes are not easy to quantify for this time segment. Since the operating room is responsible for this part of the process, the remaining part of this project will not focus on this segment of the 15 minutes response target.

From Exceedance of the Mobilisation Duration (Dispatch to Mobilised)
The main causes for an excessive Mobilisation Duration are 'Miscellaneous', 'Logistics of the post', and an 'Incorrect plotting'. In the past years the UMCG ambulancezorg has already devoted much attention in improving the Mobilisation Duration. When this part of the response time is compared to the national average mobilisation duration (Drenthe 0:44, Netherlands 1:09 for 2010) it can be observed that the region Drenthe is actually performing quite well.

From Exceedance of the Travel to Scene (Mobilised to Arrival)
Figure B.3 shows a pie-chart with the most mentioned reasons for not achieving the response time regarding the Travel to Scene (Mobilised to Arrival).

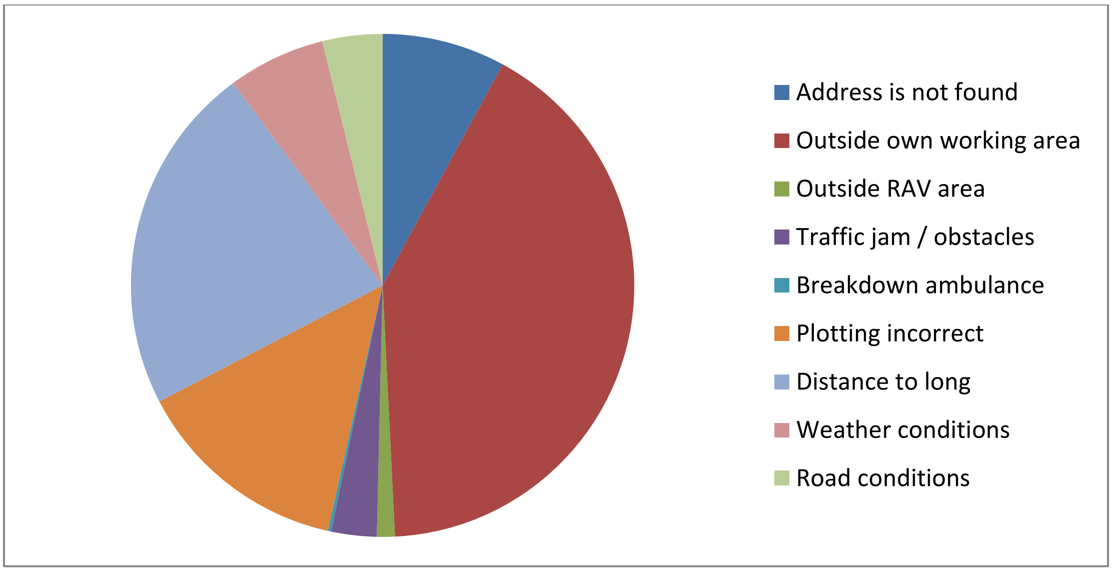

Figure B.3 Pie chart of causes of long travel to scene time

Most mentioned causes are 'Outside own working area', 'Distance to long' and 'Plotting incorrect'. The latter means that somehow the plotting device did not work or that the ambulance team forgot to plot. These deployments are not of interest.
Besides these main causes almost 10% of these exceedances are caused by not finding the address. Other reasons which are less likely to occur are issues like 'Traffic jams/ obstacles, other 'Road conditions' and 'Weather conditions'. These issues are outside the influence of the UMCG ambulancezorg.

B.3 Conclusion about validation of the problem and diagnosis

Although the specific response target itself can be questioned (see literature review chapter 3), it is clear that the response target is not obtained in the region Drenthe. This is true, especially in the more rural areas were calls for assistance are less likely to occur. Therefore this problem is certainly not a perception problem. However, the performance of the region Drenthe is actually a bit above the national average. This means that other areas face similar problems regarding this target. Therefore the 95% 15 minutes performance target may be too difficult to obtain with the current resources in practice, which might make this problem a target problem.

Although multiple regions face similar problems, the general opinion prevails that with the right resources or a more efficient system this target is attainable. This opinion together with the political pressure and the general belief 'quicker is better' makes this problem of not achieving the 95% of category A1 emergency calls within 15 minutes a real problem.

The 15 minutes response time can be divided into three different time intervals. The time segment of most interest is the travel to scene. Striking is that reasons for not obtaining the 15 minute targets are often attributed to the cause that the scene is too far away, either outside own working area or just too far away. These causes can both be related to the availability, location, and distribution of resources across the region. Therefore in order to tackle this problem it must be investigated whether the current resources can be better matched to the demand to improve the response performance.

C. Stakeholder analysis

Five groups of stakeholder can be distinguished regarding to the A1 response performance problem. These are:

- Patients
- Ambulance staff
- Health Insurance Company
- Government
- UMCG Board of directors

C.1 Mendelow's Power-interest grid

These stakeholders are mapped in Mendelow's Power-interest grid in Figure 1 depending on:

- Interest of stakeholder
- power of stakeholders

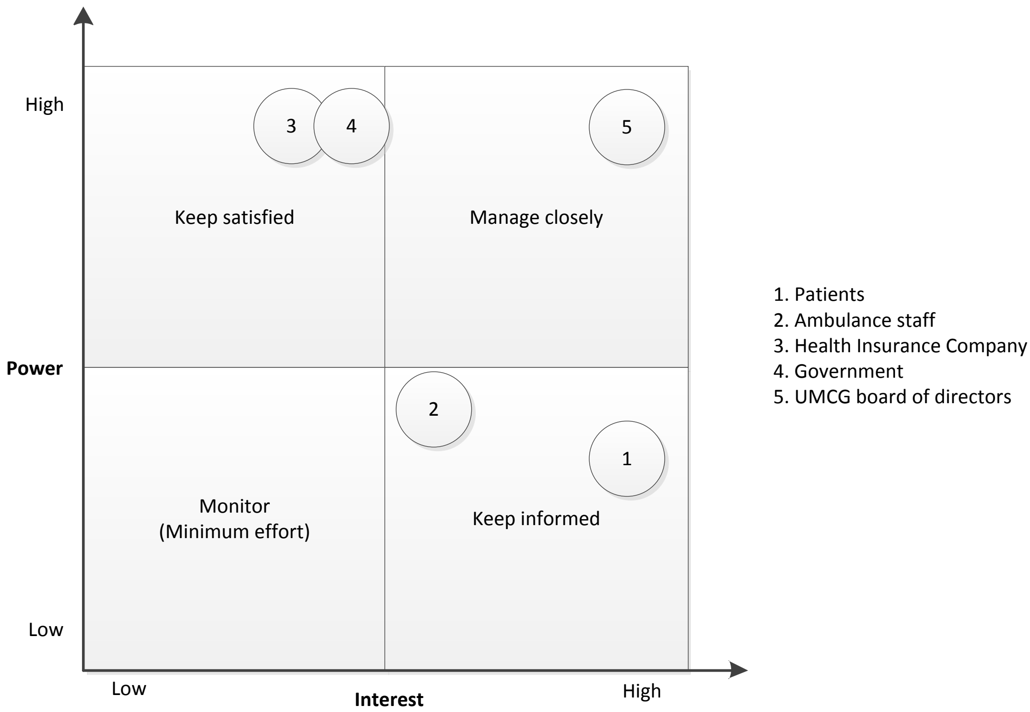

Figure C.1 Mendelow's Power-interest grid

1. Patients

Patients would like to get the best treatment possible. When the response time target is not achieved this means that patients in (potential) life-threatening situations have to wait more than 15 minutes before the ambulance team is on the scene. Longer waiting times for patients are considered to be undesirable and may result in a negative effect on the survival rate and psychical mobility of patients. Therefore patients demand high quality EMS and a fast response. However, patients have little power in actually deciding on how these aspects should be addressed. Since there power is low, and their interest is high they are placed in the lower right segment op Figure C.1.

2. Ambulance staff
Ambulance crew can be affected by findings in this research. When shifts change, they are the one that have to execute these shifts. They have moderate power, since it is not easy to find alternative staff quickly. They should be kept informed.

3. Health Insurance Company
The health insurers provide the available funding for the EMS system. They have a lot of power because in deciding which organisations receive a permit, the opinion of health insurers will be heavily weighted. They should be kept satisfied. Their goal is to provide good quality care and keep the patients satisfied at minimum costs.

4. The Government
Due to legislation (TWaz), The Ministry of Health will issue permits for a period of five years. The government should be kept satisfied. The main goal of the Government is to enable good quality care for all inhabitants of the Netherlands at minimum costs. However, the only performance indicator that is currently considered to be important is the A1 response performance.

5. UMCG board of directors
The board of directors were the one that actually decided there was a problem with the A1 response performance and that it should be investigated. They have a high level of interest and eventually make the decisions, albeit in consultation with the Health Insurance Company and (local) government. UMCG ambulancezorg benefits from a better response performance. Low response performance may damage the reputation of UMCG ambulancezorg. Their goal is to provide good quality care at minimum costs. The UMCG board of directors are placed in the upper-right segment of Figure C.1.

C.2 Summary
The goals of the different groups are pretty much aligned. All parties want to provide good quality and timely care at minimum costs. The A1 response performance and the operational costs of the resources are the performance indicators that are used to determine whether this objective is reached.

D. List of Stations

Table D.1 List of stations

Number	Address	Postal code	Place name	X,Y coordinates
306	Spijkerboorsdijk 3a	9468 CG	Annen	53.05613, 6.73545
301	Balkendwarsweg 1	9405 PT	Assen	52.99606, 6.51989
302	Romhof 6	9411 SC	Beilen	52.86290, 6.49200
303	Poolse Bevrijderslaan 102	9531 PS	Borger	52.92194, 6.78190
304	Hulsvoorderdijk 4	7741 CX	Coevorden	52.67435, 6.74579
312	De Wringer 25	7984 NL	Dieverbrug	52,84635, 6,33569
307	Van Schaikweg 6	7811 KJ	Emmen	52.77830, 6.89286
319	Kanaal B ZZ 5	7881 NB	Emmercompascuum	52.80408, 6.95911
310	dr. G.H. Amshoffweg 1	7909 AA	Hoogeveen	52.72657, 6.46077
308	Mizar 1	7891 VM	Klazienaveen	52.72797, 6.99073
311	Hoogeveenseweg 38	7943 KA	Meppel	52.69141, 6.21454
313	Sudden 2	9301 ZM	Roden	53.15023, 6.43712
998	Vriezerweg 10	9482 TB	Tynaarlo	53.08060, 6.59834

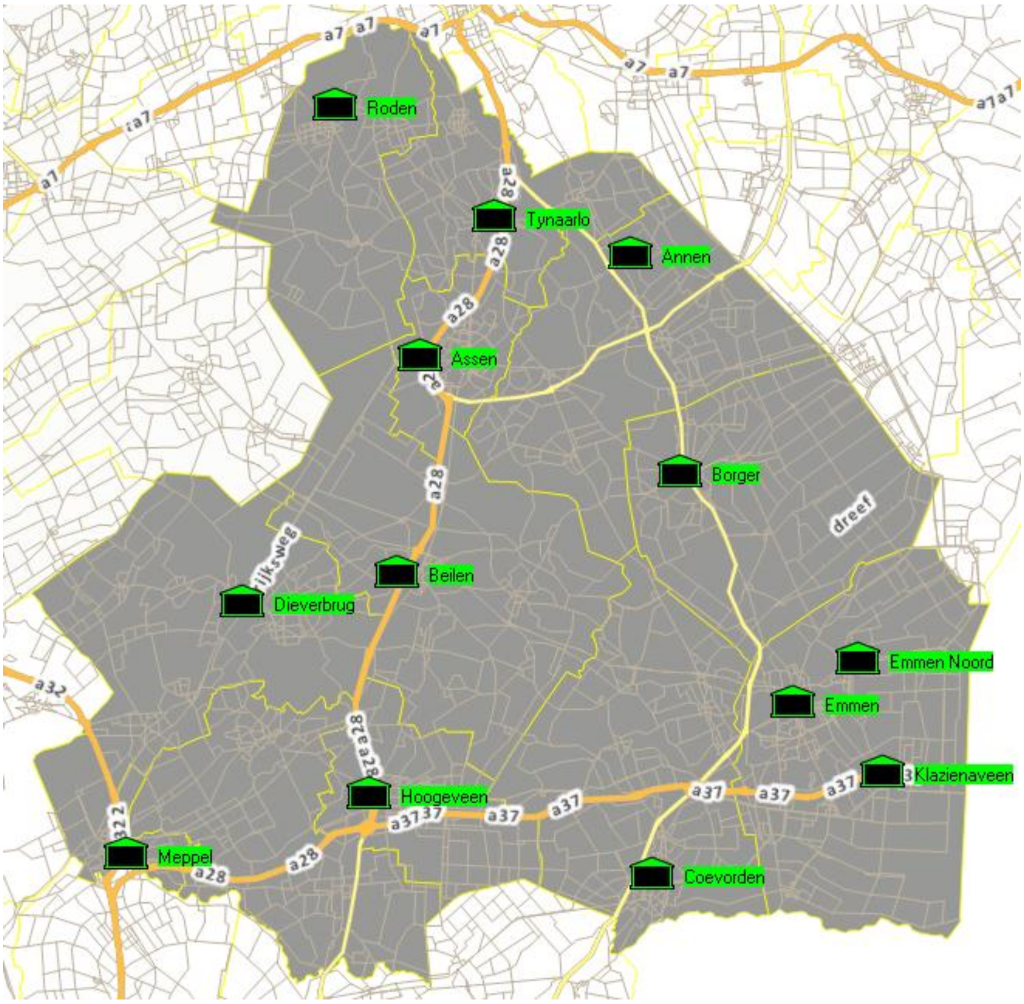

Figure D.2 Location of stations Drenthe

E. Resource schedule Drenthe

Shifts Drenthe in 2012

Ambulances	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Which days
Annen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Assen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Assen_02_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Assen_03_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Assen_04_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Assen_05_solo									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Beilen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Borger_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Coevorden_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Dwingelo_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Emmen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Emmen_02_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Emmen_03_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Emmen_04_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Emmen_05_Solo															■	■	■	■	■	■	■	■			Mon.-Fri.
EmmenNoord_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Hoogeveen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Hoogeveen_02_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Hoogeveen_03_DB									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Hoogeveen_04_D9										■	■	■	■	■	■	■	■	■							Sat.-Sun.
Klazienaveen_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Meppel_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Meppel_01_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.
Roden_01_24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	all
Tynaarlo_01_motor									■	■	■	■	■	■	■	■	■								all
Tynaarlo_02_D									■	■	■	■	■	■	■	■	■								Mon.-Fri.

Figure E.1 Resource schedule Drenthe

F. Hospitals Northern Netherlands

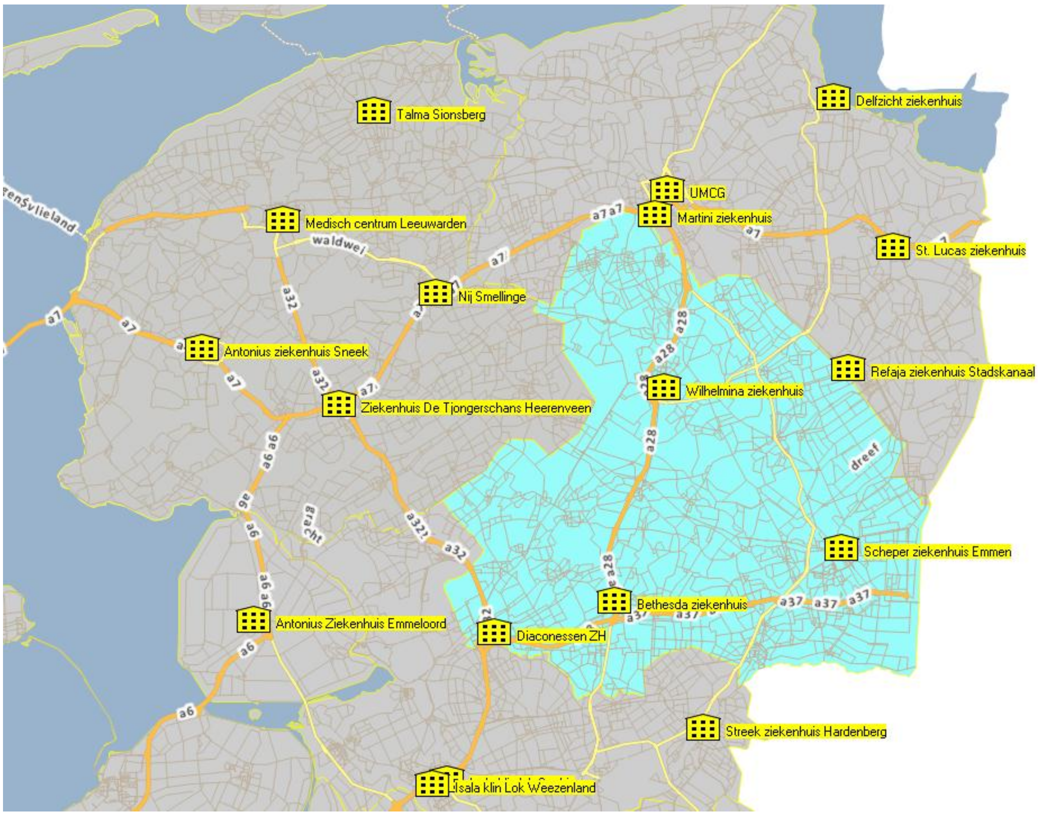

Figure F.1 Location of hospitals Northern Netherlands

G. Relationship EMS demand and A1 response performance

To test if there currently exists a relationship between demand for EMS and the A1 response performance the demand per call class (A1, A2, B1, B2) was compared to the response performance in 2011 per:

- Week. Choosing one week is appropriate since:
    - Demand is cyclic with a period of one week
    - The resource schedule is cyclic with a period of one week
- Weekdays and weekends days
    - resources and demand differ between weekdays and weekends

Table G.1 Statistics for correlation test

N	52 (weeks)	260 (weekdays)	105 (weekends)
Degrees of freedom	52-2 = 50	260-2 = 258	105-2 = 103
t-value (.05, 2-tail)	2.009	1.969	1.983
t-value (.10, 2-tail)	1.676	1.651	1.660
Standard deviation A1 performance	0.026	0.061	0.054

The critical t-value is compared to the t-value above. When the absolute critical t-value is lower than the t-value, the null hypothesis of no relationship between EMS demand and rA1 response performance cannot be rejected.

$$critical\ t = r * \sqrt{\frac{N-2}{1-r^2}}$$

Below is a reference of how to interpret the correlation coefficients. The same applies for negative correlations.

Table G.2 Guideline for how to interpret correlation coefficient r

+.70 or higher	Very strong positive relationship
+.40 to +.69	Strong positive relationship
+.30 to +.39	Moderate positive relationship
+.20 to +.29	Weak positive relationship
+.01 to +.19	No or negligible relationship

Table G.3 Statistics demand for EMS and A1 response performance (52 weeks)

Weeks	A1	A2	B1	B2	Total demand
Standard deviation	31.016	35.714	8.037	18.737	39.226
Covariance	0.114	-0.023	-0.010	-0.089	-0.009
Correlation (r)	0.14	-0.02	-0.05	-0.18	-0.01
Strength of relationship	No or negligible	No or negligible	No or negligible	No or negligible	No or negligible
t-critical	1.00	-0.18	-0.33	-1.30	-0.06
Significance (.05)	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected
Significance (.10)	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected

Table G.4 Statistics demand for EMS and A1 response performance (260 weekdays)

Weekdays	A1	A2	B1	B2	Total demand
Standard deviation	7.262	8.912	3.064	6.843	13.920
Covariance	-0.047	-0.053	0.016	-0.051	-0.135
Correlation (r)	-0.11	-0.10	0.08	-0.12	-0.16
Strength of relation	No or negligible	No or negligible	No or negligible	No or negligible	No or negligible
t-critical	-1.710	-1.565	1.345	-1.956	-2.576
Significance (.05)	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 can be rejected
Significance (.10)	r=0 can be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 can be rejected	r=0 can be rejected

Table G.5 Statistics demand for EMS and A1 response performance (105 Weekend days)

Weekends	A1	A2	B1	B2	Total demand
Standard deviation	7.329	9.129	1.192	2.394	10.240
Covariance	0.088	-0.015	0.004	-0.007	0.071
Correlation (r)	0.22	-0.03	0.07	-0.05	0.13
Strength of relation	Weak positive	no or negligible	no or negligible	no or negligible	no or negligible
t-critical	2.305	-0.307	0.689	-0.525	1.304
Significance (.05)	r=0 can be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected
Significance (.10)	r=0 can be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected	r=0 cannot be rejected

Most demand is not or negligible and not significant correlated with the A1 response performance. This means that small fluctuations in demand are not considered to be correlated with an increase or decrease in the A1 response performance with the current resources. There are, however, a few significant relationships.

- There is a very weak negative but significant (2-tailed .05) relationship between total daily demand on weekdays and A1 response performance (r = -.16).
- There is a very weak negative but significant (2-tailed .10) relationship between B2 demand and A1 response performance on weekdays (r = -.11)
- There is a very week negative but significant (2-tailed .10) relationship between A1 demand and A1 response performance on weekdays (r = -.12).
- There is a weak positive but significant (2-tailed .05) relationship between A1 demand and A1 response performance in the weekends (r = 0.22)

Most of these relationships are negative which indicates that an increase in demand is generally accompanied by a decrease in the A1 response performance.

H. Poisson process

In order to calculate the possibility for another demand within a specified timeframe a Poisson distribution is used. A Poisson distribution is appropriate since the 'arrivals' of patients is independent from one another.

"A Poisson process, extensively used in queuing theory is a counting process in which the number of events that occur within a given time period has a Poisson distribution. If λ is the rate at which these events occur, and t is the time period over which we observe these events, then the parameter of interest is λt which, to all intents and purposes, is the number of events that occurred in time t. In this case we set α=λt." (Stewart, 2009, p.124-125)

Poisson probability mass function:

$$f(k,\alpha) = p_X(k) = \begin{cases} \frac{\alpha^k e^{-\alpha}}{k!}, & k = 0,1,2,\ldots,\alpha>0, \\ 0 & otherwise. \end{cases}$$

Cumulative distribution function:

$$F(k) = Prob\{X \le k\} = e^{-\alpha} \sum_{j=0}^{k} \frac{\alpha^j}{j!}$$

Table 17 was developed based on the formulas above for different α.

I. Historic arrival rates per base

Table I.1 Arrival rate per station per hour: A1, A2, and B1 demand

	Borger	Coevorden	Emmen	Emmen Noord	Hoogeveen	Klazienveen	Annen	Assen	Beilen	Dwingelo	Meppel	Roden	Tynaarlo
0	0.12	0.13	0.26	0.10	0.21	0.14	0.12	0.40	0.08	0.05	0.17	0.12	
1	0.09	0.11	0.19	0.10	0.18	0.08	0.07	0.30	0.08	0.05	0.13	0.15	
2	0.11	0.08	0.19	0.05	0.18	0.08	0.07	0.33	0.10	0.05	0.11	0.08	
3	0.07	0.08	0.16	0.07	0.20	0.10	0.04	0.27	0.07	0.05	0.13	0.08	
4	0.07	0.08	0.18	0.07	0.13	0.09	0.04	0.23	0.04	0.01	0.15	0.09	
5	0.06	0.07	0.14	0.07	0.15	0.09	0.05	0.24	0.04	0.05	0.08	0.10	
6	0.08	0.07	0.17	0.08	0.14	0.11	0.05	0.22	0.05	0.04	0.10	0.08	
7	0.08	0.11	0.24	0.09	0.21	0.14	0.07	0.27	0.07	0.04	0.17	0.08	
8	0.15	0.15	0.85	0.14	0.52	0.23	0.15	0.76	0.14	0.12	0.52	0.20	0.15
9	0.23	0.16	0.90	0.20	0.67	0.24	0.21	0.99	0.21	0.10	0.51	0.20	0.18
10	0.21	0.25	0.97	0.24	0.62	0.26	0.21	1.00	0.21	0.18	0.53	0.29	0.23
11	0.21	0.28	0.90	0.25	0.56	0.28	0.21	1.16	0.22	0.19	0.52	0.27	0.23
12	0.29	0.27	1.03	0.25	0.70	0.28	0.22	1.07	0.28	0.21	0.53	0.30	0.25
13	0.25	0.25	0.93	0.21	0.67	0.28	0.23	1.02	0.23	0.16	0.49	0.20	0.20
14	0.22	0.24	0.76	0.24	0.65	0.29	0.21	1.01	0.22	0.18	0.45	0.22	0.23
15	0.25	0.23	0.88	0.21	0.54	0.27	0.24	0.95	0.20	0.20	0.44	0.22	0.25
16	0.21	0.19	0.79	0.21	0.53	0.27	0.18	0.90	0.24	0.16	0.36	0.25	0.16
17	0.20	0.24	0.41	0.33	0.35	0.27	0.19	0.69	0.20	0.17	0.30	0.25	
18	0.18	0.17	0.27	0.28	0.34	0.26	0.19	0.61	0.20	0.13	0.27	0.21	
19	0.16	0.21	0.34	0.27	0.29	0.23	0.19	0.68	0.21	0.15	0.28	0.21	
20	0.18	0.22	0.39	0.21	0.33	0.21	0.16	0.57	0.20	0.11	0.31	0.22	
21	0.16	0.21	0.31	0.20	0.29	0.22	0.16	0.50	0.16	0.10	0.29	0.20	
22	0.15	0.16	0.28	0.16	0.32	0.18	0.17	0.47	0.11	0.07	0.22	0.15	
23	0.12	0.15	0.25	0.15	0.22	0.15	0.12	0.36	0.07	0.09	0.17	0.15	

Table I.2 Arrival rates per station per hour: A1 demand

	Borger	Coevorden	Emmen	Emmen Noord	Hoogeveen	Klazienveen	Annen	Assen	Beilen	Dwingelo	Meppel	Roden	Tynaarlo
0	0.06	0.04	0.11	0.05	0.05	0.08	0.04	0.15	0.04	0.02	0.06	0.04	
1	0.04	0.04	0.10	0.03	0.07	0.05	0.04	0.11	0.04	0.02	0.04	0.06	
2	0.05	0.04	0.11	0.03	0.07	0.04	0.04	0.15	0.05	0.02	0.05	0.04	
3	0.04	0.04	0.08	0.03	0.09	0.04	0.01	0.10	0.04	0.02	0.07	0.03	
4	0.04	0.03	0.07	0.04	0.05	0.05	0.03	0.11	0.02	0.01	0.04	0.03	
5	0.03	0.03	0.05	0.03	0.06	0.04	0.02	0.11	0.02	0.02	0.04	0.03	
6	0.05	0.04	0.07	0.04	0.06	0.05	0.03	0.08	0.03	0.02	0.04	0.04	
7	0.04	0.08	0.13	0.04	0.13	0.08	0.03	0.11	0.05	0.02	0.09	0.03	
8	0.05	0.05	0.26	0.07	0.10	0.08	0.07	0.23	0.07	0.03	0.10	0.05	0.10
9	0.08	0.06	0.24	0.08	0.19	0.07	0.06	0.29	0.05	0.03	0.14	0.08	0.11
10	0.04	0.12	0.33	0.08	0.17	0.11	0.07	0.32	0.08	0.05	0.16	0.11	0.13
11	0.08	0.10	0.27	0.09	0.17	0.10	0.08	0.35	0.06	0.04	0.14	0.09	0.13
12	0.10	0.08	0.35	0.07	0.16	0.07	0.07	0.31	0.07	0.05	0.10	0.09	0.16
13	0.07	0.10	0.27	0.07	0.16	0.09	0.05	0.30	0.05	0.05	0.13	0.05	0.12
14	0.07	0.09	0.24	0.08	0.24	0.09	0.06	0.27	0.05	0.04	0.12	0.06	0.14
15	0.08	0.09	0.30	0.08	0.18	0.09	0.07	0.31	0.07	0.06	0.13	0.07	0.18
16	0.09	0.07	0.28	0.08	0.19	0.10	0.06	0.28	0.07	0.04	0.13	0.07	0.07
17	0.05	0.08	0.14	0.13	0.14	0.11	0.07	0.23	0.07	0.07	0.10	0.10	
18	0.07	0.08	0.11	0.10	0.13	0.10	0.07	0.22	0.07	0.03	0.11	0.06	
19	0.07	0.10	0.12	0.12	0.11	0.12	0.08	0.31	0.08	0.08	0.11	0.06	
20	0.07	0.10	0.12	0.09	0.17	0.07	0.07	0.21	0.08	0.02	0.11	0.08	
21	0.06	0.09	0.14	0.09	0.12	0.09	0.08	0.16	0.07	0.03	0.12	0.08	
22	0.05	0.08	0.14	0.08	0.15	0.06	0.08	0.16	0.04	0.02	0.07	0.05	
23	0.06	0.05	0.13	0.07	0.10	0.05	0.05	0.14	0.03	0.05	0.06	0.05	

J. Project specification

Background to the problem situation

In the Netherlands, there are a few response time field standards emergency medical service (EMS) systems should satisfy. From these standards there is particular political and public attention for serving 95% of the A1 emergency calls within a 15 minutes response time target for urgent A1 calls. In the region Drenthe were the EMS is provided by UMCG ambulancezorg the performance on this 15 minutes response time target in the years 2008, 2009, 2010, and 2012 has been 93.9%, 93.6%, 91.8%, 93,7% respectively. In most occasions, not achieving this target can be attributed to a long travel to scene time. In most cases when the target is not achieved the ambulance departs from its assigned base and the scene is just too far away from the base or the scene is outside the own working area of the assigned ambulance. This cause can be related to the location, availability and distribution of resources across the region. Therefore in order to tackle this problem it must be investigated whether the use of the current resources can be reorganised in a way to achieve the 15 minutes 95% response performance for A1-priority calls. Besides making effective use of the current resources, the EMS system should also be cost-efficient.

Besides the current issue of not achieving the 15 minutes response time target, there are autonomous growth scenarios and (possible) healthcare organisation scenarios that may impose additional pressure on the performance of the EMS system in Drenthe. Most important examples are:

- Demographic developments: the size of the population and the aging of people
- Closing down Emergency Departments (ED)
- New priority dispatching system in the control centre
- Specialisation of hospitals
- Taking over urgent calls from general practitioners

The examples above may result in a higher demand for EMS, a different demand mix for EMS, or longer driving distances for the ambulances and thereby reducing the availability of the resources in Drenthe. This additional demand can put more strain on the current resources and may have a significant effect on the performance of the EMS system.

Objectives of the simulation study

1. To suggest an EMS design that meets the 95% 15 minutes response time performance target of A1-priority calls for UMCG ambulancezorg in the region Drenthe at minimum costs.
2. To provide UMCG ambulancezorg with an analysis of the stability and sensitivity of alternative designs on the performance of the EMS system regarding different future scenarios.

Expected benefits

Simulation can have numerous advantages over real systems or other modelling approaches. (Robinson, 2004) Most important benefits in this project are:

- Costs: experimentation with the real system is very costly. Moving an ambulance station or a adding a new shift requires a large investment. With the aid of simulation software, different system configurations can be tested without investing in new resources.

- Time: it takes time before a true reflection of the performance of the EMS system can be obtained. With simulation software, results can be obtained within minutes.
- Control of the experimentation conditions: with simulation software, alternatives can be compared by controlling the conditions under which the simulations are performed. This allows for comparing experiments and excluding any external variability.
- Creating knowledge and understanding: Through simulation, one can better understand how the system behaves under certain circumstances. Therefore a simulation study may lead to more insight into the EMS system.
- Visualization and communication: The simulation can be run in interactive mode to demonstrate how the EMS system functions under certain circumstances. Besides this interactive mode, results can be shown graphically. This visualisation is proved to be a valuable tool in order to convince senior management.

Specific benefits from this project:

- A costs efficient EMS design for UMCG ambulancezorg
- Experience with newly purchased simulation software

The conceptual model:
Inputs, outputs, content (scope and level of detail), assumptions and simplifications.

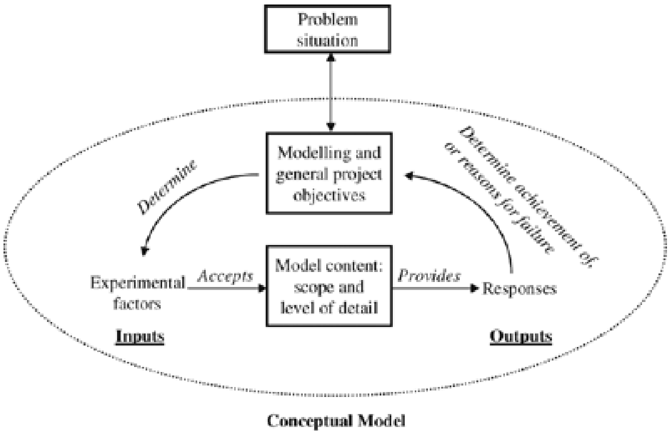

Figure J.1 A framework for designing the conceptual model (revised from Robinson, 2004)

Table J.1 Model inputs

Level	Parameter	Values	Current interpretation
Strategic/ resources	1. Number and location of stations	It is possible to create many different bases on different locations	13 different stations See Appendix D for specific locations
	2. EMS resource schedule	It is possible to expand the fleet with as many units as possible and schedule shifts all over the day. Schedule depends on: Deployment system - Tiered system - All-ALS system Type of vehicles	See Appendix E for specific schedule Deployment system Tiered system Type of vehicles

			- ALS vehicles - BLS vehicles - Rapid responders	- 25 ALS and 2 back-up ambulances - 4 BLS ambulances - Rapid responder: 1 motor 5 solo's (car)
			<u>Type of shifts:</u> - Active duty - Presence duty - Availability duty	<u>Type of shifts</u> - Presence duty 13x 24-hour shifts. ALS (sleeping at night) - Active duty: 6x 9-hour dayshifts ALS (weekdays) 4x 9-hour dayshifts BLS (weekdays) 1x 9-hour dayshift Solo (weekdays) 1x 8-hour dayshift Solo (weekdays) 1x 9-hour dayshift Motor (all days) 1x 9-hour dayshift ALS (weekend)
Tactical / policies	3.	Dispatching policy	<u>Method of call queuing</u> 5) Priority dispatching 6) First-in-first-out dispatching <u>Method of assigning an ambulance</u> - Closest dispatch - Non-closest dispatch	<u>Method of call queuing</u> Priority dispatching (CBD) <u>Method of assigning an ambulance</u> Closest with re-route enabled dispatch
	4.	Relocation strategy	- No relocation strategy - Cover specific places - Dynamic relocation	Cover specific places

Table J.2 Model outputs

Responses (to determine achievement of objectives)	- Percentage of A1 calls within 15 minutes response time - Percentage of A2 calls within 30 minutes response time - Costs of vehicles, staff and stations
Responses (to identify reasons for failure to meet objectives)	- Histogram of response times for A1 calls, mean, standard deviation, minimum and maximum - Utilization bases - Location and time of calls with travel to scene time over 12 minutes

Content (Scope and level of detail)

Table J.3 Model scope

Component	Include/exclude	Justification
Patients	Include	Patients are picked up, treated and/or transported by different ambulances
Vehicles	Include	Travel to coordinates to pick-up or bring the 'patient'
Hospitals	Include	Patients are 'brought to' of 'picked up' at the hospital if necessary
Bases	Include	Vehicles depart from their home station towards the scene or hospital
Equipment	Exclude	Does not influence response time
Roads	Include	Vehicles 'travel' over the roads
Staff	Exclude	Vehicles include staff

Table J.4 Model level of detail

Component	Detail	Include/exclude	Comment
Patients	Call class	Include	Different call classes require different responses
	Scene criticality	Include	Some patients should be transported to a hospital, while other do not
	Hospital criticality	Include	To which type of hospital the patient should be transported
	Scene (X, Y)	Include	Geographic coordinates of the scene
	Destination (X, Y)	Include	Geographic coordinates of the destination
	Call received	Include	Time and date of the call
	General characteristic (age, gender etc.)	Exclude	Do not influence response times
Vehicles	Type of vehicle	Include	Different type of vehicles offer different services
	Shift schedule	Include	Experimental factor
	Mobilisation duration	Include	Modelled as distribution, differentiated by call class and day segment
Hospitals	Location	Include	Geographic coordinates of hospital
	Hospital type	Include	Differentiated between normal hospitals, mental hospital of a nursing home
	Opening hours	Include	Some hospitals are closed during the night
Bases	Location of base	Include	Location of base determines distance to location of the call
	Capacity of base	Exclude	Assume capacity can be expanded
Roads	Speed	Include	Is important for calculating the time it takes for an ambulance to arrive at the scene under different conditions
	Direction	Include	Travel direction of the road influences the response time

Assumptions and simplifications

- Only the EMS system in Drenthe is modelled. In reality Drenthe is surrounded by other regions. In the model, only vehicles from the region Drenthe can respond to the calls in Drenthe.
- Calls are classified as A1, A1R, A2, B1 or B2. There is no distinction between different types in these call classes.

- Helicopter response is not included
- Upgrading/downgrading call priorities is not included

Experimentation: scenarios to be considered
See Appendix M for full list of scenarios and outcomes

Data requirements
Table J.5 Data requirements

Vehicles:	Shift schedule
Patients:	Historic call data
Bases:	Coordinates of bases
Hospitals:	Coordinates of hospitals

Time-scale and milestones
The simulation study is performed as part of a master thesis for the study Industrial Engineering and Management. The thesis should be completed within 30 ECTS (30*28 = 840 hour).

Obtaining accurate results
EMS systems operate 24 hours 7 days a week. The simulation model can therefore be classified as a non-terminating system. This means that there is no natural end point that determines the length of a run.
The demand for EMS is also highly unpredictable. However, at night, demand is pretty low and most vehicles are at their assigned base. When there is no demand, all vehicles are at their assigned base. Every night the system thus, more or less, returns to her initial conditions and the correlation between different periods can be neglected. This means there is no initial transient and therefore no need for a warm-up period.

In order to obtain accurate results there are two options:
- One long run
- Multiple (shorter) runs

It is with the current version of the simulation model not possible to change any seed values. Therefore it is not possible to perform multiple replications. Ideally we would like to make multiple replications to create confidence intervals of the results. Besides that it is not possible to make multiple replications, all outcomes must be recorded manually. This is time-consuming and error-prone. Therefore I will perform one single run to screen different scenarios. The dataset used to perform one single run is discussed under dataset below.
In order to determine a) the run length and b) an appropriate batch size for creating a confidence interval, a simulation with three years data was executed. The resulting A1 response performance was recorded for each week, per four weeks and per 26 weeks. Figures J.2 to J.4 show the cumulative mean A1 response performance per week, per four weeks and per 26 weeks. Note that the vertical axis for Figure J.2 differs from Figures J.3 and J.4.

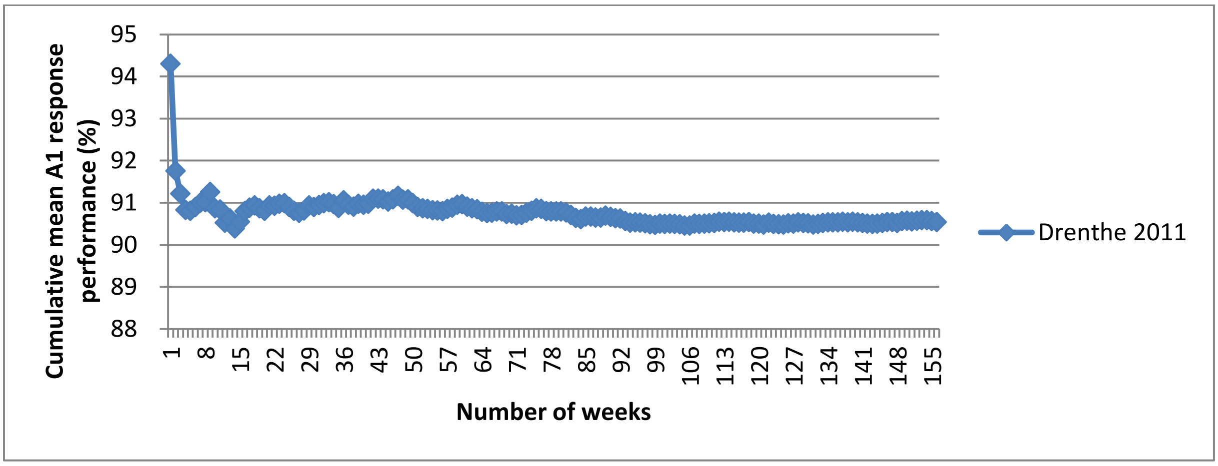

Figure J.2 Cumulative mean A1 response performance with a batch size of one week

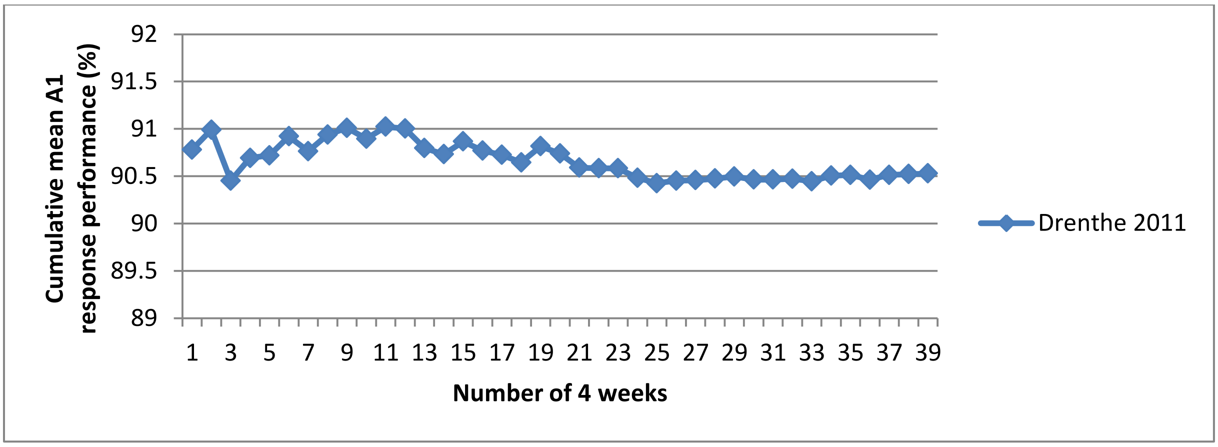

Figure J.3 Cumulative mean A1 response performance with a batch size of four weeks

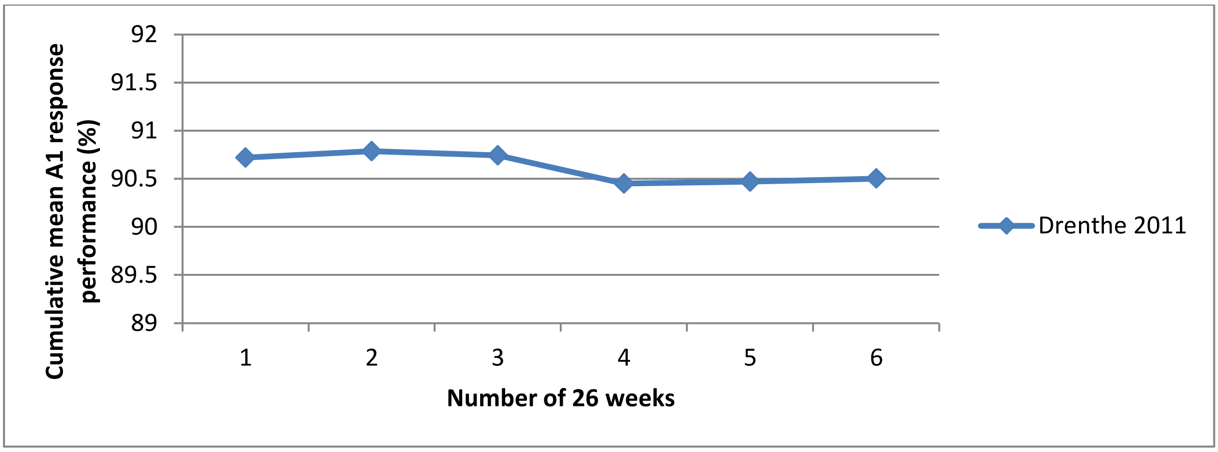

Figure 42 Cumulative mean A1 response performance with a batch size of 26 weeks

From Figures J.2 to J.4 it can be observed that the cumulative mean remains fairly constant after two years for each batch size.

Based on the data that was used to construct Figures J.2 to J.4 a confidence interval can be constructed. This confidence interval is calculated as follows:

$$t - confidence\ interval\ of\ the\ mean = \bar{X} \pm t * \frac{S}{\sqrt{N}}$$

Where:

- t is a critical value depending on the confidence level (1-α) and the degrees of freedom.
- $\bar{X}$ is the cumulative mean of the sample
- S is the standard deviation of the sample
- N is the number of observations
- α is taken to be 0.05

Table J.6 shows an overview of the statistics for each batch size. The error term in Table J.1 is defined as the half width of the confidence interval divided by the cumulative mean A1 response performance.

Table J.6 Statistics for different batch sizes

	Cumulative mean	Standard deviation	t-statistic	Half width confidence interval	Error
per week	90.539	2.512	1.975	0.397	0.00439
per four weeks	90.529	1.340	2.024	0.434	0.00480
per 26 weeks	90.502	0.467	2.571	0.490	0.00541

From Table J.1 it can be observed that for each batch size the confidence interval is approximately the same. The error term for all batch sizes is around 0.005. In order to keep the manual operations to a minimum, a batch size of 26 weeks is chosen in order to create a confidence interval of the results.

Only the scenarios that are worth further investigation are divided into equal batches to create a confidence interval. To keep the manual operations at a minimum, the model will be run for three years with a batch size of 26 weeks. A single long run of three years will take approximately 15-25 minutes to run, depending on the size of the input data. (Running Optima Predict 3.9.3 on a laptop with Intel Core 2.4 GHz, 4GB RAM)

Dataset

The only available dataset in this simulation study is historic data from UMCG ambulancezorg from 01-01-2010 to 19-10-2010. In order to obtain more reliable outcomes, a three year dataset was created based on a random sampling process from the available dataset. New calls are generated with a specific call location, call region, call received time and all the other relevant attributes (the sample fields) that match calls from the historic dataset (the match fields).

For example:

if one is sampling the call's location, then we match on "Region" and Call Class" in order that we end up with a call demand that has similar geographic locations of call demand to the historic data. For other properties (the scene duration, hospital duration, and so forth) we match on “Call Class” so that we end up with similar durations for calls that are of a similar type.

Therefore the process of sampling is as follows:

1) Given a call that you are in the process of generating:
   a) Look through all of the calls from the historic dataset, and pick out the ones that match the call you are generating
   b) Pick one call at random from the subset. The core pseudo random generator that is used for this step is the ‘Wichmann-Hill AS183’ algorithm.
   c) Then fill in the properties of the call you are generating by copying across the properties of the call you selected. It only copies the properties that are ticked in the “Sample Fields” part of the call generator setup.
2) An underlying process generates the call received time for calls to match the loaded file’s call received time trends. These are randomly generated using a ‘Non-homogeneous Poisson arrival generator’.

K. Paired-t confidence interval

To compare the outcomes of different simulation a paired-t confidence interval is used. The basic idea of this method is to create a confidence interval for the difference in two expectations. The method works as follows:

1. Compute differences per pair of outcomes (D_j)
2. Compute average difference (D_{AVG}) and variance of the difference (D_{VAR})

   $$D_{AVG} = \frac{\sum_{j=1}^{n} D_j}{n}$$

   $$D_{VAR} = \frac{\sum_{j=1}^{n} [D_j - D_{AVG}]^2}{n(n-1)}$$

3. Compute confidence interval for the difference by:

   $$D_{AVG} \pm t_{n-1,1-\alpha/2} * \sqrt{D_{VAR}}$$

If the confidence interval includes zero, there is no significant difference between the two data streams.

L. Model validation

Comparing system output data with model output data

The simulation is a trace-driven simulation. This means that the simulation is driven by historical input data. In order to validate the model, the system output data and the model output data are compared. This is the so called inspection approach as displayed in the Figure below. (Law, 2007)

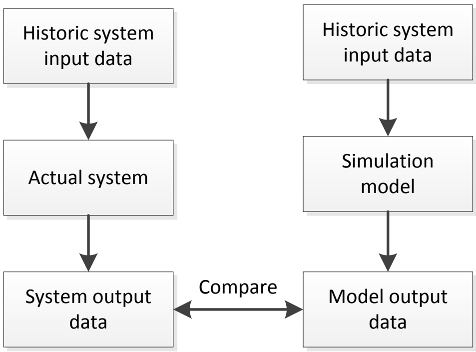

Figure L.1 The correlated inspection approach

A confidence interval is created for the A1 response performance and the average response times. The data is cut into weeks. Table L.1 presents the outcomes. For an explanation of the paired-t confidence interval see Appendix K.

Table L.1 Comparison system output data and model output data

	A1 response performance				Average response time A1			
	Historic	Model			Historic	Model		
week j	Xj	Yj	Xj-Yj	Sq.Diff	Zj	Aj	Zj-Aj	Sq.Diff
1	88.55	95.15	-6.60	60,96	9.25	8.45	0.80	0.67
2	87.62	91.47	-3.85	25,58	9.60	8.75	0.85	0.75
3	90.78	90.78	0.00	1,46	9.62	9.45	0.17	0.03
4	91.70	93.01	-1.31	6,34	9.23	8.95	0.28	0.09
5	85.14	85.43	-0.29	2,24	9.95	9.60	0.35	0.13
6	88.74	90.14	-1.40	6,80	9.75	9.40	0.35	0.13
7	91.40	91.86	-0.46	2,78	9.22	8.78	0.44	0.21
8	91.08	90.19	0.89	0,10	9.17	9.12	0.05	0.00
9	93.84	93.84	0.00	1,46	8.83	8.70	0.13	0.02
10	94.30	91.71	2.59	1,91	8.83	8.83	0.00	0.00
11	93.72	92.38	1.34	0,02	8.45	8.75	-0.30	0.08
12	92.48	93.26	-0.78	3,95	8.85	8.85	0.00	0.00
13	94.91	93.52	1.39	0,03	8.57	8.62	-0.05	0.00
14	94.26	94.34	-0.08	1,66	8.82	8.88	-0.06	0.00
15	94.63	90.91	3.72	6,31	8.52	8.83	-0.31	0.09
16	92.79	88.84	3.95	7,52	8.97	9.23	-0.26	0.06
17	92.79	89.47	3.32	4,46	8.97	9.10	-0.13	0.01
18	93.72	88.94	4.78	12,76	8.80	9.07	-0.27	0.06
19	95.87	91.78	4.09	8,31	8.82	8.98	-0.16	0.02
20	91.14	90.30	0.84	0,14	8.93	9.10	-0.17	0.02

21	93.62	92.37	1.25	0,00	8.95	9.15	-0.20	0.03
22	92.70	88.41	4.29	9,50	9.27	9.55	-0.28	0.07
23	91.57	91.16	0.41	0,64	9.10	9.35	-0.25	0.05
24	92.89	93.78	-0.89	4,40	8.47	8.60	-0.13	0.01
25	95.35	91.24	4.11	8,42	8.38	8.98	-0.60	0.34
26	92.61	89.11	3.50	5,25	8.72	9.08	-0.36	0.12
27	90.52	89.66	0.86	0,12	9.63	9.48	0.15	0.03
28	91.18	89.54	1.64	0,19	9.07	9.10	-0.03	0.00
29	94.72	90.73	3.99	7,74	8.77	9.13	-0.36	0.12
30	96.06	91.13	4.93	13,86	8.68	8.80	-0.12	0.01

	30 weeks		Without first 6 weeks	
	A1%	**A1 Average response time**	**A1%**	**A1 Average response time**
Sample mean	1.2077	-0.02	2.07	-0.14
Sum sq. Diff	204.9117	3.18	101.532	1.38
n*(n-1)	870	870	552	552
tinv	2.0452	2.0452	2.06866	2.068658
St.Dev.	0.9925	0.1236	0.8872	0.103258
LB Conf.int	0.215	-0.139	1.1828	-0.23951
RB Conf. int	2.200	0.108	2.9572	-0.03299

Results:

30 weeks:
There is a statistical significant difference between the historic data and the model for the A1 response performance. The model tends to underestimate the real achieved A1 response performance with 1.2% on average. There is no significant difference between the average response times.

Without first 6 weeks:
When the first 6 weeks are excluded there is an even larger difference between the A1 response performance in the model and in the real world. The model tends to underestimate the real achieved performance by 2.07% on average. There is also a small but significant difference in the mean response time. The mean response time in the model is on average 0.14 minutes lower than in the real world. Although significant, this difference is thus very small.

Histogram A1 response times

Besides the mean response performance and the average response times the model can also be validated by comparing histograms of the response times.

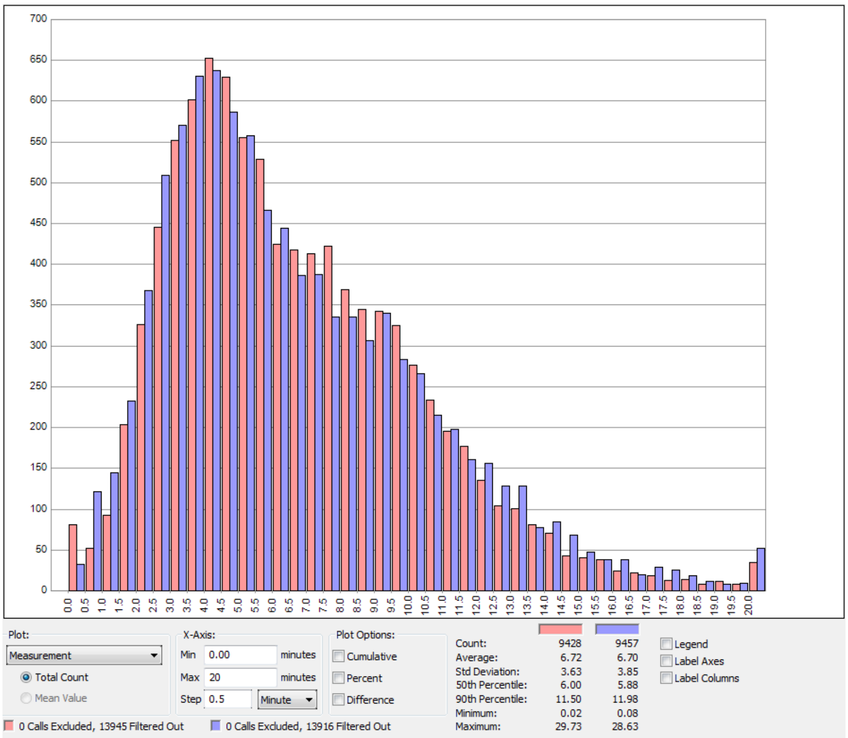

Figure L.1 Histogram A1 response times: comparison system output data and model output data

Red = historic data
Blue = model

At a first glance, the histograms look pretty similar. A closer look tells us that the model actually has more calls with a shorter response time than for the historic data. However, there are also more calls in the right tail for the model. This right tail is the reason for the lower A1 response performance compared to the historic data as identified earlier.

Utilization different posts
For every deployment the different times are registered. This includes the moment a vehicle is dispatched to a call and the moment the vehicle is again available to new calls. These deployments can be distinguished per base. This allows for calculating a utilization rate per base. It is not possible to differentiate between multiple vehicles in one base since a specific type of shift does not always use the same vehicle. Sometime a BLS shift uses an ALS vehicle; therefore the calculated utilization is an approximation of the real utilization for ALS ambulances. The utilization is calculated by dividing the total time the ALS ambulances of a base were busy serving calls by the total available time of all ALS ambulances at that base. Utilization rates for 2010 (historic and model) are presented in Table L.2.

Table L.2 Utilization rates comparison model and system

Total overview 2010	Shifts	Utilization historic	Utilization model
306 Annen	1x 24h	0.136	0.141
301 Assen	2x 24h	0.306	0.194
302 Beilen	1x 24h	0.143	0.130
303 Borger	1x 24h	0.155	0.133
304 Coevorden	1x 24h	0.151	0.160
307 Emmen	2x 24h. 2x 9h (5days)	0.330	0.263
317 Emmen Noord	1x 24h	0.132	0.129
312 Dwingeloo	1x 24h	0.093	0.122
310 Hoogeveen	1x 24h + 1x 9h	0.245	0.217
308 Klazienaveen	1x24h	0.172	0.156
311 Meppel	1x 24h + 1x 9h (5days)	0.192	0.162
313 Roden	1x 24h	0.179	0.160
998 Tynaarlo	1x 9h motor	0.074	0.100
309 Eelde	1x 9h (5days)	0.152	0.314

The utilization of ALS vehicles for the different posts is pretty close to the historic utilizations. Eelde and Assen differ because the day car of Eelde was actually part of a 24-hour shift of Assen.

M. Future demand scenarios

Table M.1 Inhabitants in percentages per age category (interpolated from Provinciale staten van Drenthe, 2012)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
0-10.	11.5%	11.4%	11.2%	11.0%	10.8%	10.7%	10.6%	10.5%	10.4%	10.3%	10.2%	10.2%	10.2%
11-20.	12.2%	12.2%	12.1%	12.0%	11.9%	11.9%	11.8%	11.8%	11.7%	11.7%	11.6%	11.5%	11.5%
21-30.	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.3%	9.2%
31-40.	11.7%	11.6%	11.4%	11.3%	11.1%	10.9%	10.8%	10.6%	10.5%	10.4%	10.3%	10.3%	10.3%
41-50.	15.7%	15.3%	14.9%	14.5%	14.2%	13.9%	13.6%	13.3%	12.9%	12.6%	12.3%	12.1%	11.9%
51-60.	14.6%	14.7%	14.8%	14.9%	15.0%	15.1%	15.2%	15.3%	15.5%	15.5%	15.6%	15.5%	15.3%
61-70.	12.6%	12.8%	13.0%	13.3%	13.5%	13.6%	13.6%	13.7%	13.8%	13.9%	14.1%	14.2%	14.4%
71-80.	7.8%	8.1%	8.5%	8.9%	9.2%	9.5%	9.8%	10.1%	10.3%	10.6%	10.8%	10.9%	11.1%
81-90.	4.0%	4.0%	4.1%	4.1%	4.2%	4.3%	4.4%	4.5%	4.6%	4.7%	4.8%	4.9%	5.0%
91->	0.6%	0.6%	0.7%	0.7%	0.8%	0.8%	0.9%	0.9%	1.0%	1.0%	1.0%	1.1%	1.1%
Total inhabitants Drenthe (x1.000)	**491**	**492**	**492.1**	**492.2**	**492.3**	**492.4**	**492.5**	**492.6**	**492.7**	**492.8**	**492.9**	**492.8**	**492.5**

Table M.2 A1+A2 demand per 1000 people per age category for 2005-2011

A1&A2	2005	2006	2007	2008	2009	2010	2011
0-10.	7.15	7.47	7.67	8.51	8.31	10.06	10.70
11-20.	16.68	18.38	21.11	21.32	22.16	20.88	20.66
21-30.	23.68	26.91	28.91	29.32	29.69	31.84	30.84
31-40.	19.51	20.19	21.27	22.27	21.86	24.77	24.02
41-50.	23.43	25.21	26.68	27.71	27.32	30.17	29.19
51-60.	31.85	34.06	34.63	36.68	36.95	39.84	42.03
61-70.	51.87	55.78	58.68	58.57	60.31	61.08	60.96
71-80.	116.97	120.71	122.71	124.16	123.09	128.05	124.44
81-90.	221.08	240.05	247.77	250.03	257.75	233.25	237.91
91->	316.34	367.86	375.97	403.59	382.05	318.74	354.00

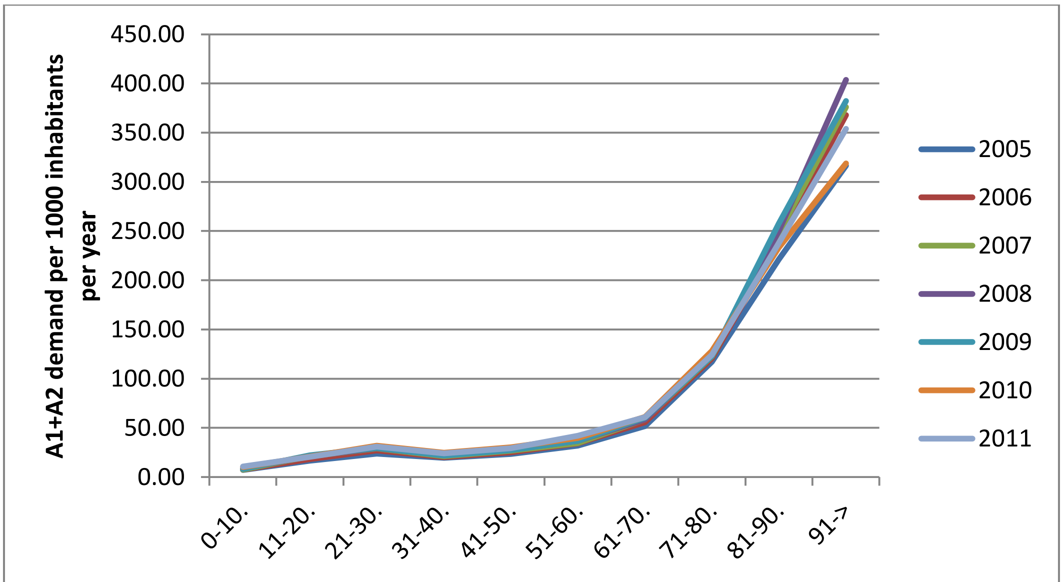

Figure M.1 A1+A2 demand per age category for 2005 - 2011

N. Simulation output

Table N.1 Simulation output round 1

Problem	Solution	Scenario number	Scenario	A1 %	A1 average	A2%	A2 average
			Baseline	90.50	9:20	94.47	15:18
1.1 The rural area between Hoogeveen, Beilen and Emmen is badly covered by stations.	1.1a Move surrounding stations towards the uncovered area	101	Hoogeveen to A37 exit 1 south	90.78	9:16	94.58	15:17
		102	Hoogeveen to A37 exit 1 north	90.87	9:14	94.66	15:20
		103	Coevorden to Dalen (N854/N34 west)	90.84	9:20	94.57	15:16
		104	Emmen to N34/N381	90.70	9:21	94.68	15:13
		105	Beilen to N856/N381	90.48	9:18	94.35	15:18
		106	Assen to Assen south	90.43	9:12	94.46	15:07
		107	Beilen to Trainstation Beilen	90.23	9:17	94.45	15:13
		108	Borger to Schoonoord	89.76	9:25	94.12	15:30
	1.1b Split surrounding (multiple vehicle) stations towards the uncovered area	109	Day ALS Hoogeveen to A37 exit 1 north	90.45	9:17	94.51	15:20
		110	24hour ALS Hoogeveen to A37 exit 1 north	90.61	9:14	94.54	15:17
		111	Day ALS Emmen to N34/N381	90.62	9:18	94.47	15:16
	1.1c Create new station in the uncovered area (needs additional vehicle)	112	1x ALS24h Assen to Assen south	90.39	9:16	94.54	15:08
		113	Zweelo (ALS) (08:00-17:00)	90.66	9:15	94.55	15:12
		114	Zweelo (solo) (08:00-17:00)	90.77	9:17	94.53	15:12
		115	Witteveen (ALS) (08:00-17:00)	90.89	9:16	94.60	15:13
		116	Witteveen (solo) (08:00-17:00)	90.55	9:17	94.52	15:12
		117	Westerbork (ALS) (08:00-17:00)	90.64	9:15	94.61	15:11
		118	Westerbork (solo) (08:00-17:00)	90.47	9:17	94.51	15:10
1.2 Not all stations are positioned strategically to provide coverage for other stations	1.2a Move stations towards exits from highways or other fast roads in order to provide coverage for other stations	121	Annen to Gieten (N34/N33)	90.44	9:17	94.41	15:19
		122	Hoogeveen to A37/A28 south	90.74	9:16	94.56	15:19
		123	Dieverbrug to Uffelte	90.48	9:20	94.42	15:19
		124	Dieverbrug to Ruinen	90.16	9:21	94.24	15:21
		125	Klazienaveen to Nieuw Amsterdam (A37 exit 5 south)	90.76	9:17	94.58	15:14
		126	Emmen to Emmen north	90.44	9:27	94.58	15:23
		127	Emmen to Emmen south	90.94	9:19	94.77	15:13
		128	Assen north + Assen south	90.67	9:09	94.62	15:04
		129	Emmen to N34/N381	90.70	9:21	94.68	15:13
		130	Hoogeveen to A37 exit 1 south	90.78	9:16	94.58	15:17
		131	Hoogeveen to A37 exit 1 north	90.87	9:14	94.66	15:20
		132	Coevorden to Dalen (N854/N34 west)	90.84	9:20	94.57	15:16
2.1 In Tynaarlo there is only a day shift (08.00-17.00). Therefore this area is more vulnerable in the evening and at night.	2.1a Create additional shifts at Tynaarlo	201	Weekend day shift (ALS)	90.43	9:20	94.57	15:18
		202	Weekend day shift (solo)	90.49	9:20	94.49	15:15
		203	Evening shift (ALS)	90.74	9:16	94.48	15:21
		204	Evening shift (solo)	90.65	9:17	94.55	15:15
		205	Evening+weekend (ALS)	91.12	9:13	94.65	15:22
		206	Evening+weekend (solo)	90.94	9:14	94.61	15:11
		207	Day to 24hour shift (ALS)	91.41	9:10	94.67	14:56
	2.1b Move surrounding stations and/or shifts closer to Tynaarlo	208	Assen to Assen North	90.17	9:16	94.50	15:17
		209	Roden to Norgerweg/Nieuweweg	89.94	9:21	94.31	15:21
		210	Roden to Roderweg/N372	90.53	9:22	94.43	15:23
		211	Roden to Roden east	90.38	9:20	94.47	15:19
		212	1x24hour ALS Assen to Assen north	90.68	9:10	94.50	15:11
2.2 There is only one BLS vehicle in Emmen, while B2 demand is the highest in Emmen. Therefore ALS ambulances in Emmen may serve too many B2 calls which negatively affects the A1	2.2a Move one BLS vehicle from Assen to Emmen	221	BLS from Assen to Emmen	90.43	9:19	94.53	15:15
	2.2b Locate BLS shifts at the hospitals to minimize travel distance	222	BLS at hospitals	90.31	9:20	94.49	15:17
	2.2c Locate all BLS units in a central place (Beilen)	223	All BLS in Beilen	90.54	9:19	94.53	15:16

performance in this area.	2.2d Create new BLS shifts	224	Emmen	90.46	9:19	94.61	15:16
		225	Hoogeveen	90.54	9:19	94.49	15:16
		226	Meppel	90.35	9:19	94.57	15:16
2.3 The deployment system is possibly not optimal. (There are other deployment systems described in the literature)	2.3a Use an all-ALS system	231	4 BLS to 4 ALS	90.78	9:16	94.65	15:09
		232	BLS and solo to ALS	90.82	9:08	94.50	15:13
		233	No solo	89.36	9:19	93.99	15:22
2.4 There are not enough resources (ALS, BLS, rapid responders) to handle the simultaneously of calls.	2.4a Add resources were there are many calls with a response time over 15 minutes (larger places)	241	Hoogeveen (ALS) (weekdays 08:00-17:00)	90.63	9:18	94.49	15:14
		242	Roden (ALS) (weekdays 08:00-17:00)	90.58	9:18	94.48	15:14
		243	Emmen (ALS) (weekdays 08:00-17:00)	90.52	9:18	94.59	15:14
		244	Coevorden (ALS) (weekdays 08:00-17:00)	90.61	9:16	94.60	15:10
		245	Assen (ALS) (weekdays 08:00-17:00)	90.52	9:21	94.61	15:13
		246	Meppel (ALS) (weekdays 08:00-17:00)	90.50	9:18	94.49	15:15
		247	Hoogeveen (solo) (weekdays 08:00-17:00)	90.65	9:18	94.48	15:14
		248	Roden (solo) (weekdays 08:00-17:00)	90.40	9:18	94.61	15:14
		249	Emmen (solo) (weekdays 08:00-17:00)	90.51	9:18	94.53	15:17
		250	Coevorden (solo) (weekdays 08:00-17:00)	90.70	9:17	94.69	15:11
		251	Assen (solo) (weekdays 08:00-17:00)	90.26	9:21	94.48	15:16
		252	Meppel (solo) (weekdays 08:00-17:00)	90.54	9:19	94.48	15:15
		253	Hoogeveen (ALS) (weekdays 17:00-23:00)	90.67	9:17	94.48	15:15
		254	Roden (ALS) (weekdays 17:00-23:00)	90.68	9:17	94.51	15:15
		255	Emmen (ALS) (weekdays 17:00-23:00)	90.54	9:18	94.54	15:19
		256	Coevorden (ALS) (weekdays 17:00-23:00)	90.61	9:18	94.51	15:17
		257	Assen (ALS) (weekdays 17:00-23:00)	90.63	9:18	94.57	15:17
		258	Meppel (ALS) (weekdays 17:00-23:00)	90.50	9:18	94.55	15:15
		259	Hoogeveen (solo) (weekdays 17:00-23:00)	90.63	9:18	94.49	15:15
		260	Roden (solo) (weekdays 17:00-23:00)	90.67	9:18	94.52	15:16
		261	Emmen (solo) (weekdays 17:00-23:00)	90.47	9:20	94.50	15:17
		262	Coevorden (solo) (weekdays 17:00-23:00)	90.47	9:19	94.58	15:18
		263	Assen (solo) (weekdays 17:00-23:00)	90.51	9:19	94.53	15:15
		264	Meppel (solo) (weekdays 17:00-23:00)	90.67	9:18	94.61	15:15
		265	Hoogeveen (ALS) (weekends 09:00-18:00)	90.51	9:18	94.53	15:15
		266	Roden (ALS) (weekends 09:00-18:00)	90.41	9:18	94.51	15:15
		267	Emmen (ALS) (weekends 09:00-18:00)	90.72	9:16	94.51	15:13
		268	Coevorden (ALS) (weekends 09:00-18:00)	90.70	9:19	94.61	15:14
		269	Assen (ALS) (weekends 09:00-18:00)	90.60	9:19	94.54	15:15
		270	Meppel (ALS) (weekends 09:00-18:00)	90.71	9:19	94.49	15:14
		271	Hoogeveen (solo) (weekends 09:00-18:00)	90.67	9:19	94.45	15:16
		272	Roden (solo) (weekends 09:00-18:00)	90.48	9:19	94.51	15:16
		273	Emmen (solo) (weekends 09:00-18:00)	90.75	9:17	94.47	15:14
		274	Coevorden (solo) (weekends 09:00-18:00)	90.66	9:18	94.59	15:16
		275	Assen (solo) (weekends 09:00-18:00)	90.65	9:19	94.62	15:16
		276	Meppel (solo) (weekends 09:00-18:00)	90.60	9:19	94.51	15:16
2.5 All dayshifts end at the same time (17.00), this large volatility between supply and demand around this time may have a negative impact on the performance.	2.5a Extent x shifts with y minutes to decrease the volatility between supply and demand	281	BLS + 30min	90.53	9:18	94.59	15:18
		282	BLS + 60min	90.62	9:19	94.44	15:17
		283	ALS + 30min	90.53	9:18	94.57	15:17
		284	ALS + 60min	90.87	9:17	94.48	15:16
		285	ALS,BLS + 30min	90.64	9:18	94.54	15:16
		286	ALS,BLS + 60min	90.96	9:17	94.53	15:16
3.1 In practice, reroute-enabled dispatch does not happen as protocol prescribes	3.1a Use different reroute-enabled dispatching policies	301	Reroute-enabled dispatching Order: 1:A1,2:A2,3:B1,4:B2	91.59	9:07	93.89	15:28
		302	Reroute-enabled dispatching Order: 1:A1,2:A2,3:B1,B2	91.65	9:06	94.03	15:30
		303	Reroute-enabled dispatching Order: 1:A1,2:A2,B1,B2	91.78	9:05	93.86	15:31
		304	Reroute-enabled dispatching Order 1:A1,A2, 2:B1,B2	90.64	9:17	94.54	15:15
3.2 There is a closest dispatching protocol which minimizes the respond time for the current calls	3.2a Introduce non-closest dispatching protocol. (will not be tested)						

but neglects overall response performance.							
3.3 ALS vehicles are too often sent to lower priority calls, this decreases their availability for urgent A1 calls.	3.3a Do not send (all) ALS vehicles to the scene for lower priority calls	311	1 carposts: only A1 (08:00-17:00)	90.02	9:24	87.13	18:37
		312	1 carposts: only A1, A2 (08:00-17:00)	90.28	9:20	94.57	15:20
		313	1 carposts: only A1, A2, B1 (08:00-17:00)	90.40	9:20	94.41	15:19
		314	HEMA: only A1 (1x24hour shift) (08:00-17:00)	90.53	9:18	93.38	16:04
		315	HEMA: only A1, A2 (1x24hour shift) (08:00-17:00)	90.42	9:20	94.42	15:19
		316	HEMA: only A1, A2, B1 (1x24hour shift) (08:00-17:00)	90.49	9:19	94.41	15:19
		317	HEMA+C+R: only A1 (1x24hour shift) (08:00-17:00)	90.85	9:15	91.63	16:58
		318	HEMA+C+R: only A1,A2 (1x24hour shift) (08:00-17:00)	90.51	9:19	94.56	15:17
		319	HEMA+C+R: only A1,A2,B1 (1x24hour shift) (08:00-17:00)	90.56	9:20	94.53	15:17
		320	HEMA: only A1 (08:00-17:00)	89.75	9:26	89.18	18:01
		321	HEMA: only A1,A2 (08:00-17:00)	90.35	9:22	94.48	15:21
		322	HEMA: only A1,A2,B1 (08:00-17:00)	90.31	9:21	94.49	15:19
		323	1 carposts: only A1 (17:00-23:00)	89.75	9:25	90.18	17:16
		324	1 carposts: only A1, A2 (17:00-23:00)	90.06	9:21	94.42	15:18
		325	1 carposts: only A1, A2, B1 (17:00-23:00)	90.42	9:20	94.43	15:18
		326	HEMA: only A1 (17:00-23:00)	90.89	9:16	93.59	16:04
		327	HEMA: only A1, A2 (17:00-23:00)	90.51	9:19	94.51	15:16
		328	HEMA: only A1, A2, B1 (17:00-23:00)	90.62	9:19	94.47	15:18
		329	HEMA+C+R: only A1 (1x24hour shift) (17:00-23:00)	90.87	9:15	92.37	16:39
		330	HEMA+C+R: only A1,A2 (1x24hour shift) (17:00-23:00)	90.67	9:19	94.41	15:17
		331	HEMA+C+R: only A1,A2,B1 (1x24hour shift) (17:00-23:00)	90.65	9:19	94.52	15:18
		332	1 carposts: only A1 (23:00-08:00)	90.37	9:21	92.58	16:04
		333	1 carposts: only A1, A2 (23:00-08:00)	90.23	9:21	94.53	15:17
		334	1 carposts: only A1, A2, B1 (23:00-08:00)	90.54	9:20	94.45	15:17
		335	HEMA: only A1 (23:00-08:00)	90.56	9:19	93.61	15:42
		336	HEMA: only A1, A2 (23:00-08:00)	90.41	9:20	94.44	15:17
		337	HEMA: only A1, A2, B1 (23:00-08:00)	90.55	9:19	94.49	15:17
		338	H,R only A1 (23:00-08:00)	90.38	9:19	94.16	15:30
		339	H,R only A1,A2 (23:00-08:00)	90.30	9:19	94.42	15:17
		340	H,R only A1,A2,B1 (23:00-08:00)	90.45	9:20	94.48	15:17
3.4 Rapid responders are not dispatched effectively	3.4a Solo's only respond to A1 calls	341	Solo only A1	90.59	9:18	94.16	15:16
4.1 There is not a good relocation strategy	4.1a Cover high demand bases	401	1. Emmen (08:00-23:00)	90.38	9:18	94.48	15:16
		402	1. Emmen, 2. Assen (08:00-23:00)	90.59	9:18	94.46	15:16
		403	1. Emmen, 2.Assen, 3. Hoogeveen (08:00-23:00)	90.61	9:17	94.56	15:14
		404	1. Emmen, 2. Assen, 3. Hoogeveen, 4. Meppel (08:00-23:00)	90.92	9:15	94.65	15:12
		405	1. Emmen, 2. Assen, 3. Hoogeveen, 4. Meppel,5. Tynaarlo (08:00-23:00)	91.22	9:12	94.77	15:08
		406	1. Emmen, 2. Assen, 3. Hoogeveen, 4. Meppel,5. Coevorden (08:00-23:00)	91.12	9:12	94.77	15:08
		407	1. Emmen, 2. Assen, 3. Hoogeveen, 4. Meppel,5. Tynaarlo, 6.Coevorden (08:00-23:00)	91.40	9:10	94.78	15:05
		408	1. Emmen, 2. Assen, 3. Hoogeveen, 4. Meppel, 5. rest (08:00-23:00)	90.88	9:17	94.56	15:12
		411	1. Emmen, 2. Assen, 3, Hoogeveen, 4. Meppel (08:00-17:00)	90.72	9:18	94.55	15:15
	4.1b Cover high demand areas	421	ETH (Highway) (08:00-23:00)	91.47	9:13	94.75	15:20

Table N.2 Simulation output round 2

Scenario	Combination of scenarios	A1 %	A1 average	A2%	A2 average	yearly operational costs (x1000)
Reroute-enabled dispatching + relocation strategy						
1001	303+405	91.94	9:01	93.97	15:22	86
1002	303+407	92.39	8:57	94.33	15:18	118
1003	303+421	92.61	9:00	94.03	15.32	175
Reroute-enabled dispatching + moving stations						
1011	102+125+303	92.48	8:34	94.13	15:17	0
1012	102+127+303	92.51	9:00	94.20	15:27	0
1013	102+132+303	92.21	9:01	94.15	15:32	0
1014	102+125+132+303	92.67	8:59	94.24	15:32	0
Reroute-enabled dispatching + additional capacity						
1021	206+303	92.21	9:00	94.03	15:24	120
1022	273+303	91.70	9:24	93.93	15:27	54
1023	284+303	91.95	9:03	93.87	15:30	80
1024	206+273+303	92.26	8:59	94.14	15:19	174
1025	206+284+303	92.37	8:57	94.12	15:23	200
1026	206+284+273+303	92.58	8:54	94.17	15:18	254
Reroute-enabled dispatching + relocation strategy + moving stations						
1031	102+303+407	92.56	8:54	94.37	15:23	118
1032	125+303+407	92.60	8:57	94.33	15:28	118
1033	127+303+407	92.81	8:57	94.45	15:23	118
1034	102+127+303+407	93.09	8:52	94.53	15:27	118
1035	102+125+303+407	92.93	8:51	94.34	15:19	118
1036	102+132+303+407	93.16	8:53	94.39	15:24	118
1037	102+125+132+303+407	93.23	8:52	94.38	15:23	118
1038	102+127+132+303+407	93.10	8:55	94.51	15:25	118
1039	102+125+127+303+407	92.96	8:55	94.45	15:22	118
1040	102+125+132+303+405	93.08	8:55	94.47	15:24	86
1041	102+127+303+405	93.08	8:53	94.48	15:18	86
1042	102+125+127+303+405	92.84	8:56	94.44	15:25	86
1043	102+125+303+421	92.78	8:57	94.19	15:34	175
1044	102+127+303+421	92.63	8:59	94.35	15:34	175
1045	102+125+132+303+421	92.85	8:59	94.25	15:37	175
Reroute-enabled dispatching + moving stations + additional capacity						
1051	102+127+206+303	92.99	8:54	94.38	15:33	120
1052	102+127+284+303	92.83	8:57	94.30	15:43	80
1053	102+127+273+303	92.91	8:57	94.37	15:38	54
1054	102+132+206+303	92.86	8:55	94.24	15:25	120
1055	102+125+206+303	92.68	8:52	94.24	15:20	120
1056	102+132+125+206+303	93.31	8:53	94.29	15:26	120
1057	102+132+125+284+303	92.98	8:57	94.19	15:32	80
1058	102+132+125+273+303	92.88	8:57	94.23	15:29	54
1059	102+132+125+284+273+303	93.25	8:55	94.25	15:27	134
Reroute-enabled dispatching + relocation strategy + additional resources						
1061	206+303+407	92.72	8:54	94.27	15:14	238
1062	273+303+407	92.55	8:56	94.31	15:14	172
1063	284+303+407	92.61	8:56	94.23	15:17	198
1064	273+284+303+407	92.92	8:53	94.36	15:13	252
1065	206+303+421	92.82	8:58	94.24	15:28	295
1066	273+303+421	92.54	8:58	94.19	15:27	229
1067	284+303+421	92.87	8:57	94.10	15:32	255
1068	206+284+303+421	93.17	8:54	94.35	15:25	375

O. Comparison different scenarios

alpha = 0.05
n = 6

Table O.1 Outcomes solutions

J (half a year)	Current EMS design (Aj)	Solution 1 (Xj)	Solution 2 (Yj)	Solution 3 (Zj)
1	90.72	93.35	93.09	92.59
2	90.85	92.86	93.61	93.35
3	90.66	93.55	93.36	93.67
4	89.57	92.30	92.60	92.53
5	90.55	92.55	92.36	93.13
6	90.66	93.38	93.83	93.72
Average	90.50	93.00	93.14	93.17
Left bound Conf. Int.	90.01	92.47	92.54	92.62
Right bound Conf. Int.	90.99	93.53	93.74	93.71

Table O.2 Difference between solutions

Current EMS design and solution 1		Current EMS design and solution 2		Current EMS design and solution 3		Solution 1 and solution 2		Solution 1 and solution 3		Solution 2 and solution 3	
Xj-Aj	Sq.Diff	Yj-Aj	Sq.Diff	Zj-Aj	Sq.Diff	Yj-Xj	Sq.Diff	Zj-Xj	Sq.Diff	Zj-Yj	Sq.Diff
2.63	0.018	2.37	0.073	1.87	0.629	-0.26	0.163	-0.76	0.859	-0.50	0.274
2.01	0.237	2.76	0.014	2.50	0.027	0.75	0.368	0.49	0.105	-0.26	0.080
2.89	0.155	2.70	0.004	3.01	0.120	-0.19	0.111	0.12	0.002	0.31	0.082
2.73	0.054	3.03	0.152	2.96	0.088	0.30	0.025	0.23	0.004	-0.07	0.009
2.00	0.247	1.81	0.689	2.58	0.007	-0.19	0.111	0.58	0.171	0.77	0.558
2.72	0.050	3.17	0.281	3.06	0.157	0.45	0.094	0.34	0.030	-0.11	0.018

Table O.3 Confidence interval of difference between solutions

	Current EMS design and solution 1	Current EMS design and solution 2	Current EMS design and solution 3	Solution 1 and solution 2	Solution 1 and solution 3	Solution 2 and solution 3
D_{AVG}	2.50	2.64	2.66	0.14	0.17	0.02
Left bound Conf. int	2.09	2.12	2.19	-0.29	-0.34	-0.45
Right Bound Conf. int	2.91	3.16	3.14	0.58	0.67	0.50
Difference significant?	Yes	Yes	Yes	No	No	No