Reducing the response time of Fire Department Amsterdam-Amstelland

The impact of civilian aid workers

Daan Schönberger

Master Thesis

Utrecht, November 2021

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Abstract

The goal of this project was to quantify the possible reduction of the response time of the FDAA by using civilian aid workers. This was done because the FDAA has a rough target to deploy 100,000 civilian aid workers by the start of 2030.

The research was mainly focused on creating an algorithm to model the responses of civilian aid workers. This was done by using a Poisson point process to model the response time distribution followed by sampling response times via Inverse Transform Sampling. Every area in the safety region has its own response time distribution. The following information was necessary to model these distributions:

- Total number of civilian aid workers present in the safety region.
- Acceptance rate, i.e., the fraction of available volunteers that on average will respond to an incident.
- Location distribution of civilian aid workers.
- Area size.

The setup to quantify the impact of the civilian aid workers was as follows. The simulator of the FDAA samples incidents and response times of the FDAA crews. Having information about the incident locations made it possible to sample response times of the civilian aid workers on these incidents. Therefore, it was possible to compare the two response times. As the FDAA has no active civilian aid workers deployed, some information needed to be estimated. Such as the number of total civilian aid workers. To showcase the impact of such variables, different scenarios were created.

On average the response time of the civilian aid workers was better than the FDAA in every scenario, even when "only" 10,000 civilian aid workers were deployed. Promising results are already obtained when 50,000 civilian aid workers are present in the region, which yields **an improvement on the response time by almost 4 minutes** on average. Furthermore, the balance between the acceptance rate and the total available civilian aid workers was important. The results were positive when the multiplication of both was above 1,000. Another view is that having civilian aid workers responding on bikes reduces the response time by a minute on average.

In conclusion the deployment of civilian aid workers can greatly reduce the response time of the FDAA. Therefore, putting it in practice should be a goal for the FDAA in the up and coming period. To do this, a few topics should be covered first. What are the tasks civilian aid workers can do at an incident location and to which incident types can civilian aid workers be deployed? The follow-up question is which equipment they need. When all these questions are answered, a further research topic could be to let civilian aid workers first travel to an equipment location and from there move to the incident location. An equipment location could be public buildings which are strategically located around the safety region.

Preface

During the last seven months I performed my research project at the Fire Department Amsterdam-Amstelland. This project was conducted to finish my Master Business Analytics at the Vrije Universiteit Amsterdam. The aim of the project was to show the obtained skills which were obtained via the Master Business Analytics. This external project was a combination of business optimization and data science focused on improving the response time of the fire department using civilian aid workers.

I want to thank Guido Legemaate for being my external supervisor. I very much enjoyed our coding sessions and the challenges we tackled together. Your happy attitude towards me and the project itself was truly inspiring. I have learned so many practical skills purely because you took your time to help me. In addition, I wish to thank my supervisors for their guidance. Firstly, prof. dr. Rob van der Mei who proposed this project and brought me into contact with the FDAA. Moreover, for his suggestion on mathematical models, his positive attitude and the great feedback. Secondly, dr. Rikkert Hindriks for being my second reader and taking his time to review my master thesis.

Apart from this, I want to thank the Information Management team at the FDAA. I felt right at home from the get go. Last but not least, I want to thank Hidde Schönberger for explaining some mathematical models to me and sparring with me on several mathematical subjects.

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Chapter 1

Introduction

1.1 About the FDAA

The Fire Department Amsterdam-Amstelland (FDAA) is one of the most active fire brigades of the Netherlands. The total area of the FDAA is "only" $282km^2$, but this area has a very high population density. It consist of six municipalities: Aalsmeer, Amstelveen, Amsterdam, Diemen, Ouder-Amstel and Uithoorn. These six municipalities have a total of 1 million inhabitants and 2 million visiting tourists every year. In addition, the region the FDAA has to cover is visited daily by thousands of people who come to work. Figure 1.1 shows the total region where the FDAA is responsible for the safety of the people.

The FDAA is not only deployed to extinguish indoor and outdoor fires, but also for resuscitation or freeing of people who are trapped in an elevator or the occupants of cars that have hit the water. Another major task is advising to prevent fires from happening. This can be done by checking fire alarms in public buildings and giving presentations about preventing dangerous situations. The FDAA consists of around 1100 employees. Roughly 450 of these are active firemen and -women. They are present at barracks and can respond immediately to incoming calls. The second group consists of around 300 volunteers, who are on call from home. This group is called volunteers or part-timers. They will travel to the barracks when an incident is reported and from there respond like a full-time firefighter. The third group is the supporting staff. For example, the Information Management (IM) team for which this paper is written. The FDAA has a total of 18 barracks in its region and these are operational 24/7, but are not staffed 24/7.

Figure 1.1: Service area of the FDAA

1.2 Research context

The FDAA has to respond quickly to dangerous emergency situations where every second counts. Being on time (or not) can be vital. Therefore, it seems logical that the FDAA wants to reduce the response time to incidents. By law, the FDAA has to respond to certain incident types within a given target time. An important performance metric is the percentage of incidents that are covered within the target time. This problem can be linked to the goals of the FDAA for the year 2030. The FDAA set several goals for 2030, one of them is that the FDAA wants to have 100,000 civilian aid workers (from here on named volunteers) by the start of 2030. This is a so called rough target. This research is a starting point to find the benefits of having volunteers helping the FDAA. This research can be placed in the "Innovation" tab of the Information Management team. The benefit of having a network of volunteers is that it's fine-meshed, but the disadvantage is that the volunteers won't be available all the time.

1.3 Problem statement

The FDAA wants to know what the potential influence of volunteers is on the response time. The best and most straightforward way is to measure this by comparing the response times of FDAA units and volunteers. Therefore, the main goal of this project is the following:

> *What will the impact be on the response time if volunteers are responding to incidents as well?*

It is not possible to answer the above question directly. Hence, a few sub-questions are stated below to assist answering the main question.

1. How to model the geographic locations of volunteers at any moment in time?

2. What is the total chain of events for a civilian aid worker?
3. Which model/algorithm can be used to find the response times of volunteers?

By answering the above questions an algorithm can be designed to model the total process of a civilian aid worker responding to an incident. Answering the main question of this project will then be straightforward because we compare the response time of the FDAA units with the response time of the volunteers. The practical research of this paper will be done by simulation, because the FDAA has no active data on volunteers. This is due to the fact that this is a goal of the FDAA and not yet implemented.

To answer the main question by simulation, the following scenarios will be covered and analysed:

1. Variability in total available volunteers.
2. Variability in acceptance rate for the volunteers.
3. Changes in the geographical distribution of the volunteers.

The results of these simulations will give an answer to the following questions:

1. How many volunteers do we need?
2. What is the minimal acceptance rate volunteers need to have to impact the response time? This question will naturally be followed up by the question: is this acceptance rate plausible?
3. Where do we need to position the volunteers around the city so that the effect of their work is maximized? In other words: where do the FDAA need to recruit more volunteers?

1.4 Reading guide of this paper

In chapter 2 the literature research is conducted. This will focus on previous FDAA research, but also the use of volunteers in different settings. Chapter 3 describes the methodology section of this paper. It will explain the algorithm(s) used to model volunteers. The implementation and the decisions that were made during the process will be explained in detail. The data needed for this research is discussed in chapter 4. This will be followed by chapter 5 where the results will be presented. Next, chapter 6 will give a summary of the results as well as some conclusions. Finally, chapter 7 will give recommendations and discuss some interesting ideas for further research.

Chapter 2

Literature Research

This chapter will focus on related research. Section 2.1 will be devoted to the previous work done at the FDAA. Section 2.1 will be followed by covering information about several volunteer implementations.

2.1 Previous FDAA research

As described in the previous chapter, responding as fast as possible is extremely important for the FDAA. To look for improvements in performance, the FDAA has done a lot of data research in the past few years. It seems logical from section 1.3 that information about future incidents is key. A first exploratory data analysis was done by Novackova [2013]. The analysis was mostly done on predicting the number of incidents in a given time lap. The added value of the research is that a model was advised that was predicting the number of incidents in a long-term perspective. This is useful for the FDAA because the schedules for firefighters are made well in advance. Novackova [2013] advised to use an ARIMA (1,0,1) model to predict the number of incidents per day. This was quite surprising because the ARIMA model has no seasonal component in comparison to a SARIMA model.

Another important topic is forecasting the so called "busy days" for the FDAA. In 2017, a research was conducted by de Deijn [2017] to predict the busy days and what kind of vehicles were needed per barrack for those days. The busy days were mostly provoked by heavy rain and bad weather in general. A Generalized linear model (GLM) had the best score to predict the number of incidents, but a Random Forest (RF) model achieved better results on busy days. Given the fact that busy days are important for the FDAA, an Ensemble Averaging model was chosen which had 80% GLM and 20% RF. This worked well for small incidents, but for big incidents the lack of data made the model not perform well on these incidents. Another result is that big incidents - where at least six trucks are needed - can be modelled by an inhomogeneous Poisson process.

Next up is a paper written in 2019 by van den Bogaert [2019] who developed a simulator tool that models incidents and the corresponding response from the FDAA. Via the simulator, the FDAA is capable of evaluating tactical and strategic decisions.

Another important result of the research by van den Bogaert [2019] is the prediction of incident locations. First the author clustered on demographic relations in the safety region. After obtaining the clusters, it could be related to incident patterns. A hand full of models were created to predict the incident locations for a period of 1 year based solely on demographic data. These models were compared to a baseline model which was the current way of working at the FDAA back then. The author concluded that the region could be summarized in 6 different geographic profiles and that it was possible to make 3 pairs of profiles which held the same incident count and distribution over the different incident types. To find the incident pattern of an incident type and its location, it works best to look at the facilities around a location. Furthermore, the geographic data can be used to predict the locations of incidents in a year and the number of incidents per location better than the baseline model based on historical data. By combining the response time distribution and the incident location distribution, it was possible to simulate incidents and the FDAA responding to these incidents.

The value for the FDAA is that the simulator software has an easy implementation and can be modified in a few ways which are convenient for the FDAA. Firstly, the input data consist of information about the incidents, deployments, fire station information and vehicle location. These four files are the only input data needed. The software automatically merges the incident and deployment data and is able to make a prediction for the upcoming incidents for a period given by the user. By being able to change the fire station information, the FDAA is capable of checking the impact of closing a station or adding one. Furthermore, the allocation makes it possible to simulate scenarios were the number of fire trucks is changed. The simulator will be used for this research as it is capable to simulate incidents and the response of the FDAA on these incidents.

Another way to improve the response time is by correct allocation of resources. This was done in 2020 by Usanov [2020]. A problem that can arise during an incident is that a gap can occur in the coverage. This multiplies when a big incident happens and multiple trucks are deployed to this incident. Normal practice was sending the closest truck to an incident, but this is not always the optimal decision. Using a Markov Decision Process (MDP) in combination with policy iteration the author shows that "the fraction of late arrivals can be significantly reduced by deviating from current practice" [Usanov, 2020]. Due the complexity of this optimal policy, it is hard to compute on realistic data, and therefore an heuristic was created which comes close to the optimal policy and requires less computations.

2.2 Modelling volunteer research

Using volunteers to reduce response time is not a recently developed idea, but it is in the context of the Fire Brigade. Therefore, this section will mostly cover topics used in the ambulance care sector where volunteers are already taking part in reducing the response time.

The ambulance sector has already a lot of applications running that aid them to react quicker to incidents. A first research was conducted in Sweden in 2011 by Ringh et al. [2011]. They used the mobile phone positioning system to locate volunteers and dispatch them if they were within a certain radius of the incident. Studies were done both by simulation and real-life practice. During simulation volunteers were dispatched if they were within 350 meters and during real-life practice volunteers were dispatched within a radius of 500 meter. The results clearly show the impact on the response time as during simulation the response time declined with 2 minutes and 20 seconds on average. During the real-life testing 46% of the cases produced a volunteer arriving before the ambulance.

In 2014, an experiment was done were volunteers received a text message if a (potential) cardiac arrest happened within 1km [Zijlstra et al., 2014]. Certain volunteers were also instructed to first retrieve an AED - which were distributed among the city - before they would travel to the incident. In 850 cases, between 2010 and 2013, at least 1 volunteer responded and in 738 cases at least 1 AED was available. There were 184 cases were a volunteer was first asked to retrieve an AED. These cases where a volunteer plus an AED was needed resulted in earlier defibrillation on average of 2 minutes and 39 seconds. This shows the impact of volunteer responding in combination with placements of AED's around the city.

In 2020, research by Stieglis et al. [2020] was done to find the impact of available volunteers and AED's per incident. For every case, the available volunteers and AED's per km^2 were calculated. The increase in available volunteers in the region resulted in a decrease in median time of first shock from 10 minutes and 39 seconds to 8 minutes and 20 seconds. This also resulted in more defibrillation within 6 minutes. Increasing the density of available AED's resulted in a median time decrease from 10 minutes and 39 seconds to 8 minutes and 17 seconds. When looking at the impact of having at least two AED's available in the region the impact was insignificant on the median time to shock, but having at least 10 volunteers in the region had a positive impact on the median time to shock. Therefore, they suggest having at least 10 available volunteers in a km^2 region to reduce the response time significantly.

In the same year a real-life study was conducted on the impact on volunteer first responders (VFR) on an island by using GPS tracking [Sarkisian et al., 2020]. They compared response times of the Emergency Medical Service with 3 VFR's which were recruited upon an emergency. In 85% of the cases the volunteer arrived before the medical services. The median response time decreased from 10 minutes and 13 seconds to 4 minutes and 46 seconds. The use of smartphone GPS tracking has a very positive influence on the response time and using VFR's, in hard-to-reach regions for medical services, should be implemented.

By observing the articles above, it becomes clear that volunteers can have a huge impact on the response times. Important factors are the density of the volunteers surrounding an incident and ergo the total number of volunteers. The question remains: How is it possible to model these volunteers around an incident? This has been done in 2021 by van den Berg et al. [2021]. They model the volunteers surrounding an incident following a Poisson point process and derive the analytical expression for the response time distribution. Another important result is the possibility to calculate the ideal volunteer distribution. Most of the time, this distribution is unknown and has to be estimated, but the authors give a clear overview that optimization is very much tractable in these kind of situations. Chapter 3 gives a clear insight into these methods.

Another topic that is important is the volunteer response delay. An important assumption in volunteer response modelling is that the closest volunteer is dispatched to an incident [Smith et al., 2017]. This is only done if the volunteer is within a certain distance from the incident. The total response time consists of two components. The response delay and the travel time. The response delay consists of three elements. First is the calling delay, i.e., the delay between the time of an incident and the moment an incident is reported to the authorities. This is followed by the triage and dispatch delay. This is the time between the call to the authorities and the moment a volunteer is dispatched. Note: dispatched means assigned and not yet walking. The final component is the volunteer acceptance delay. This is the time between dispatching and the actual start of walking by the volunteer. This combined is the whole pre-trip delay formulated by Smith et al. [2017].

Chapter 3

Methods

This chapter will give an overview of the methods used for this research. First, the setup will be explained followed by an overview of which variables we need before modelling. Also an explanation of the models used will be given. Furthermore, different test settings will be explained.

3.1 Setup

The goal is to give an insight into the effect on the response time by using volunteers. The best way to compare the response time of the FDAA and volunteers is by using historical data. Sadly, this data is not available as there is no current practice of the FDAA using volunteers. Therefore, the way to go to compare the results is by using the simulator created by van den Bogaert [2019] to generate responses from the FDAA to incidents and use volunteer modelling like van den Berg et al. [2021] to create the responses from volunteers. This makes it possible to compare the response times of different groups (FDAA and volunteers) on the same incident.

3.2 Modelling volunteers

This section is devoted to show how to model volunteers around an incident as described by van den Berg et al. [2021]. First, the basic principle is that a volunteer is available when the person is present in the region and willing to accept a notification. Throughout this chapter, the term region is used to describe the whole safety region of the FDAA. This region can be divided into sub-regions which will be called areas. In their paper van den Berg et al. [2021] assume an application on a mobile phone. This seems reasonable to assume in the setting of the FDAA. Another assumption is made that volunteers are distributed throughout the region via a spatial Poisson point process. A spatial Poisson point process assumes that the total available volunteers does not depend on the call volume. This seems acceptable as the average volunteer only receives 1 call per year [Pijls et al., 2019]. To further justify their choice for a spatial Poisson point process, van den Berg et al. [2021] looked at historical results. Theory shows that certain spatial point processes can be modelled as a Poisson point process [Kingman, 1992], [Barbour et al., 1992]. Proposition 1 of Chapter 3 by van den Berg et al. [2021] shows that when n is large, then a spatial Poisson process is well suited, where n represents the total volunteers available in the safety region. The full proof can be found in their paper, but the important assumption is equation 3.1. This shows that if n is large enough then a point process N_n converges weakly to a Poisson point process. Where N_n is the point process that gives the random number of volunteers in the region. That is,

$$\lim_{n \to +\infty} \sum_{i=1}^{n} a_i(n) v_i(B) = \mu(B) \tag{3.1}$$

The left hand side of the equation has a sum over all available volunteers i in region B and takes their individual acceptance rate a and location distribution v into account to calculate the available number of volunteers in region B. Sadly, this personal information is not available. Hence, the right hand side of the equation is necessary to model the volunteers in region B. The advantage of having a Poisson point process is that the mean μ of region B can be used to model the number of available volunteers close to an incident in region B. Although it is not necessarily important to show how each individual contributes to the mean μ, it gives some useful insight to define $\mu = n\alpha v$, where n indicates the total number of volunteers in the region which are active, a shows the acceptance rate, so the fraction of calls that are accepted by volunteers on average, and v is the volunteer distribution. This shows in what way the total number of volunteers are geographical distributed.

As described in chapter 2, it is important to obtain the volunteer response time distribution. The pre-trip delay, which is mentioned in chapter 2, will be denoted as τ_v and assumed to be constant. The total response time of the closest volunteer will be denoted as a random variable $\mathrm{T}_v(l)$. Remember that in chapter 2 the assumption was made that the closest active volunteer will respond to an incident. The variable l denotes the location of an incident.

Let's say a region $B(l, t)$ is the region B surrounding an incident where a volunteer can reach location l of an incident within t minutes. This is then logically followed by wanting to know the number of volunteers within this region B. This is done by using the result of equation 3.1. To approximate the number of volunteers within t minutes of location l the mean of the Poisson process is taken by $\mu(B(l, t)) = nav(B(l, t))$. Using a Poisson process makes it possible to calculate the probability that the response time is smaller than t. Equation 3.2 shows this probability.

$$\mathbb{P}(\mathrm{T}_v(l) \leq t) = 1 - \exp(-\mu(B(l, t))). \tag{3.2}$$

This equation is justified because of two relations. First, van den Berg et al. [2021] use the fact that the response time is smaller or equal to t if and only if a volunteer is present in set $B(l, t)$. If no volunteer would be present then it would be impossible to have a response time smaller or equal to t. Secondly, a Poisson random variable $\mathbb{Z}$ with mean x has a following probability of having at most the value 1.

$$\mathbb{P}(\mathbb{Z} \leq 1) = 1 - \exp^{-x} \tag{3.3}$$

Combining equation 3.3 with the fact that we need at least one volunteer in region $B(l, t)$ gives equation 3.2.

To calculate $B(l, t)$, in-between steps need to be taken. Given that a volunteer walks with a velocity w in km/min. The distance d_t is then the maximal distance a volunteer can cover within t minutes, where t is the pre-trip delay plus the walking time. Moreover, note that $t > \tau_v$. This is because the pre-trip delay is always present for volunteers. The relation between the distance and response time can then be described by $d_t = w(t - \tau_v)$.

Another important assumption made is that the volunteer density is constant throughout the area. This is done because the response time t is so small. Equation 3.2 can be rewritten to the following:

$$\mathbb{P}(\mathrm{T}_v(l) \leq t) = 1 - \exp(-\mu(B(l, t))) = 1 - \exp(-\mu_l \pi d_t^2) \tag{3.4}$$

It is important to note that this is now the probability for a certain location l. Every location has its own corresponding μ. Equation 3.4 allows it to take the cumulative density function (CDF) for every area. To gain the probability density function (PDF) - for every area - the CDF needs to be differentiated. This is done by the following steps:

$$\frac{\partial}{\partial t}[1 - \exp(-\mu_l \pi d_t^2)] \tag{3.5}$$

$$= \frac{\partial}{\partial t}[1 - \exp(-\mu_l \pi w^2 (t - \tau_v)^2)] \tag{3.6}$$

$$= \exp(-\mu_l \pi w^2 (t - \tau_v)^2) * 2\mu_l \pi w^2 (t - \tau_v) \tag{3.7}$$

After obtaining the CDF and PDF, the remaining question is how does one sample from the distribution? A technique called **Inverse Transform Sampling** will provide an answer. The first step is to take the inverse of the CDF. Let x be the probability that the response time is lower or equal to t.

$$x = 1 - \exp(-\mu_l \pi w^2 (t - \tau_v)^2) \tag{3.8}$$

$$t = \tau_v + \sqrt{\frac{\log \frac{1}{1-x}}{\mu_l \pi w^2}} \tag{3.9}$$

The value of x ranges between 0 and 1 in equation 3.8. Taking the inverse of the CDF means the output is now t which is the value we need to take a sample from. The input of the inverse is the output of the CDF. Therefore, generating a random number between 0 and 1 will produce a sample value for t which has the underlying PDF.

Every incident location l will be in a certain area in the region. All areas can have a different value for μ_l. This is because $\mu_l = n\alpha v_l$. The first two variables n and α are the same, but the difference comes in when inspecting v. This variable shows how the volunteers are geographically located around the region. Equation 3.4 shows the probability per area, but this is not the unconditional distribution for response times. To obtain this, a relative probability λ needs to be incorporated. It shows the probability an incident occurs in location l, where $\sum \lambda_l = 1$.

$$\mathbb{P}(\mathrm{T}_v \leq t) = \sum_{l \epsilon L} \lambda_l \mathbb{P}(\mathrm{T}_v(l) \leq t) \tag{3.10}$$

The left hand side of equation 3.10 shows that the location parameter is not present. Thus, it is the probability for the total region. The right hand side on the other hand has two variables depending on the location l. The equation takes the sum over all locations. Inside the summation, a probability of an incident arising in location l is multiplied with the probability of this location. Therefore, the unconditional distribution of volunteer response times can be seen as a weighted sum over all distributions of volunteer response times per location. The weights in this case are the relative probabilities λ.

The FDAA has no historical data on the location of volunteers, and therefore, it is hard to make an indication. Luckily, an optimization method was created to find the ideal volunteer distribution for the total region [van den Berg et al., 2021].

3.3 Optimal volunteer distribution

From equation 3.4 it is clear that we want to maximize μ_l for every location l, because a bigger μ yields more available volunteers and therefore quicker response times. Increasing μ can be done in three ways, because $\mu_l = n\alpha v_l$. To increase μ one can increase the number of total volunteers n, increase the acceptance rate of the volunteers α or increase the volunteer distribution v. Clearly the volunteer distribution is not something in direct control of the FDAA, but it can give a clear insight in which regions additional volunteers are needed, which is then easily explained to recruiters of volunteers.

The goal is to find the optimal volunteer distribution v, considering an incident demand λ per location. The objective function is the response time which we want to minimize. The target time will be denoted as τ. Dividing the total number of available volunteers of location $l(n\alpha v_l)$ by the area of location $l(a_l)$ gives the density of available volunteers in a location l. Given this fact, the following density of available volunteers can be constructed.

$$\mathbb{P}(\mathrm{T}_v \leq \tau) = \sum_{l \epsilon L} \lambda_l \mathbb{P}(\mathrm{T}_v(l) \leq \tau) = \sum_{l \epsilon L} \lambda_l \exp(-\pi d_t^2 n\alpha v / a_l) \tag{3.11}$$

The right hand side can be minimized under the restrictions that $\sum v_l = 1$ and $0 < v_l < 1$. The Karush-Kuhn-Tucker condition implies that a greedy algorithm is best suited for optimization, because the function is separable and each part of the sum is convex and decreasing in v_l [van den Berg et al., 2021]. The marginal benefit is the value it gains by increasing the volunteer mass in location l with a very small portion. The marginal benefit can be written as follows:

$$\lambda_l \pi d_\tau^2 n\alpha / a_l \exp(-v_l \pi d_\tau^2 n\alpha / a_l) \tag{3.12}$$

The marginal benefit is the derivative of the late rate for every location l. This rate shows how much a location l gains in response time if extra volunteer mass is added. Let us investigate how this algorithm works. The algorithm initializes all $v_l = 0$. Next up, a set I is created by calculating equation 3.12 for every v_l. This set contains the locations which gain the most by having extra volunteers. A small margin ϵ is added to every v_l in set I until the sum of all $v_l = 1$ or a new location joins the optimal set using equation 3.12.

3.4 Scenarios

The variables in table 3.1 are needed to calculate the response time. It is clear that there are a lot of different scenarios to discuss/explore. As stated by the Commander of the FDAA, the

Variable	Meaning
n	The total number of volunteers in the whole region
a	The acceptance rate of the volunteers across the region
v_l	The volume of the volunteers are represented in location l
w	The pace a volunteer can move in km/min
τ_v	The expected pre-trip delay in minutes
λ_l	The incident rate in location l

Table 3.1: Variables needed for volunteer response time calculation

ideal situation would be around 100,000 volunteers. An acceptance rate of 0.1 seems logical in the Netherlands from previous volunteer research [Wikipedia, 2021]. The acceptance rate shows the average probability that a volunteer responds to an incident. This is a value between 0 and 1. The pre-trip delay is 3 minutes and the volunteers can walk with a pace of 6 km/hr on average, which is 0.1 km/min. The optimal volunteer mass is calculated by the algorithm stated in section 3.3. The incident rate λ per region is provided by the FDAA. Table 3.2 gives an oversight of all scenarios tested. All these scenarios have the optimal volunteer mass v calculated by the algorithm in section 3.3. To see if this optimal volunteer mass improves the result, it is compared against a volunteer mass proportional to the inhabitants of the areas. Chapter 5 will give the results of these scenarios.

	Variables			
Scenario	n	α	w	τ_v
1	100,000	0.1	0.1	3
2	50,000	0.1	0.1	3
3	10,000	0.1	0.1	3
4	100,000	0.05	0.1	3
5	100,000	0.01	0.1	3
6	100,000	0.1	0.2	3
7	100,000	0.1	0.1	4
8	100,000	0.1	0.1	2

Table 3.2: Different scenarios to simulate

3.5 Metric for comparison

The goal is to reduce the response time. Therefore, the difference of the response times between the FDAA and the volunteers is calculated. If there is no impact on the response time, e.g. the FDAA is quicker than the volunteers, the gain will be set to 0. This leads to results which are 0 or positive and shows the gain by having volunteers. The average gain will be presented per scenario and per location in the form of a heat map.

3.6 Overview of methods

Every scenario has the same incident locations and types over a period of three years. This gives plenty of different incident locations and types to compare the results. Given all the information provided in this chapter, it is possible to simulate the whole process of a volunteer responding to an incident. It begins with having the incidents and the response of the FDAA, followed by choosing the parameters of a scenario. The next step is to calculate the optimal volunteer distribution and is followed by calculating the volunteer distribution around an incident location l. This provides a sample of a volunteer responding to an incident. This makes it possible to compare the response times and this can be visualized.

Chapter 4

Data

This chapter will give an overview of the data used. Most of the data is used for the input of the simulator [van den Bogaert, 2019]. This chapter is split up into a section for the incident data (section 4.1), the response time data (section 4.2) and the data for the optimal volunteer distribution (section 4.3). The data gathered covers a period from the 5th of January 2008 to the 14th of October 2021. Starting 2008, the FDAA safety region was created as it is known now. Therefore, it seems logical to use the data from that point onward.

4.1 Incidents

The FDAA uses several incident types. In table 4.1 below the number of incidents are shown per incident type. The incidents that will be simulated will have these types. This is important, because it is possible that different incident types require different responses by the FDAA in terms of dispatching a suitable fire truck. Another important aspect is the number of incidents per month. Figure 4.1 shows that January and December have more incidents compared to the other months. In the case of the Netherlands, this can be explained because around New Year's Eve a lot of fireworks are set off which cause a lot of incidents.

Incident type	Incidents
OMS melding	23,083
Assistentie Ambulance	21,067
Buitenbrand	19,845
Meten / overlast / verontreiniging	13,875
Liftopsluiting	11,904
Reanimeren	11,373
Hulpverlening algemeen	11,174
Binnenbrand	10,427
Extreem weer	10,136
Brandgerucht	6,541
Assistentie Politie	6,492
Automatisch of optisch alarm	3,991
Buitensluiting	3,297
PAC melding	3,266
Afhijsen	3,266
Nacontrole	2,763
Hulpverlening Dieren	2,658

Incident type	Incidents
Persoon te water	1,669
Dier te water	1,083
Beknelling / bevrijding	956
Voertuig te water	524
Hulpverlening water algemeen	355
(Inter)Regionale bijstand	103
Brandbare gassen	66
Hulpverlening Luchtvaart	23
Overige gevaarlijke stoffen	20
Uitval systeem of voorziening	17
Overig brand	14
Letsel eigen personeel	13
Overige hulpverlerning	10
Oefening of test	5
Brandbare vloeistoffen	4
Loos Alarm	1
Buiten dienststelling	1

Table 4.1: Number of incidents per incident type (in Dutch)

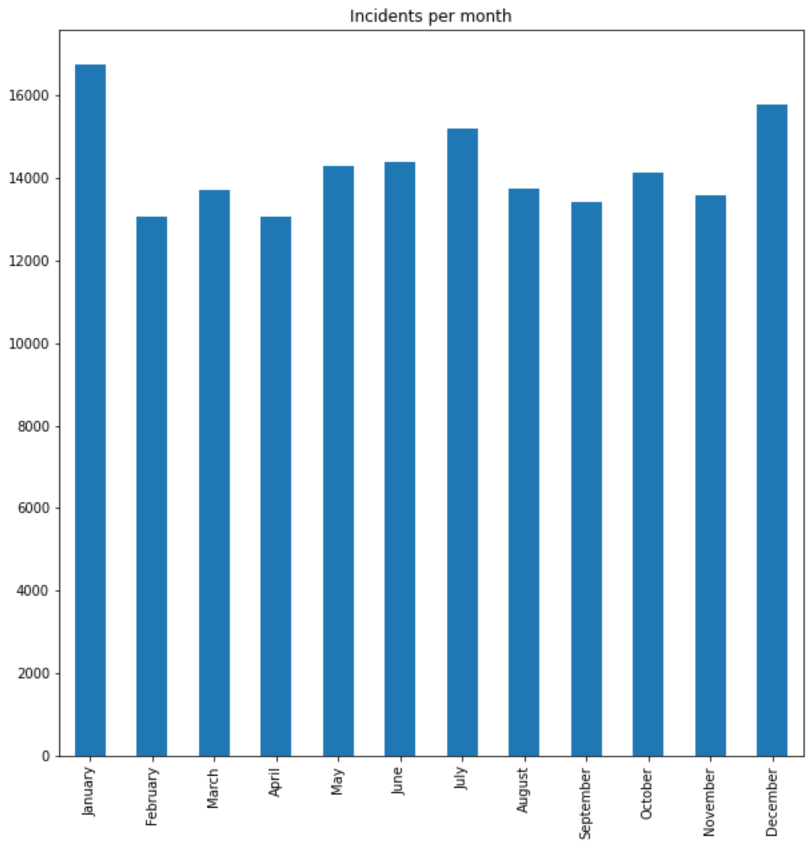
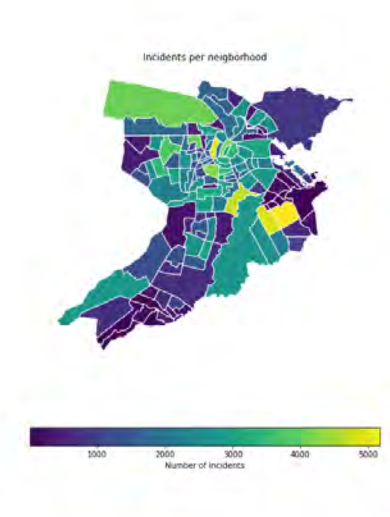


Figure 4.1: Total number of incidents per month since 2008

Besides the type of incidents and the monthly period it can also be interesting to look at the geographical distribution of these incidents. Figure 4.2 shows the number of incidents per neighbourhood and the number of incidents in a neighbourhood compared to the number of inhabitants of this neighbourhood. The neighbourhoods in the centre of Amsterdam have the most incidents. Another important fact is that a few neighbourhoods, like "Westelijk Havengebied" (top left) and "Ouderkerk aan de Amstel" (bottom right) have a high incident count, which can be attributed due to their large size. The incident rate per m^2 is therefore not that high. This can also be further clarified by the incidents vs inhabitants plot. It shows that a lot of regions have a similar incident to inhabitant ratio, which is around 5 inhabitants per incident. Of course, a few outliers are detected of neighbourhoods which have a lot of incidents compared to their corresponding inhabitants.



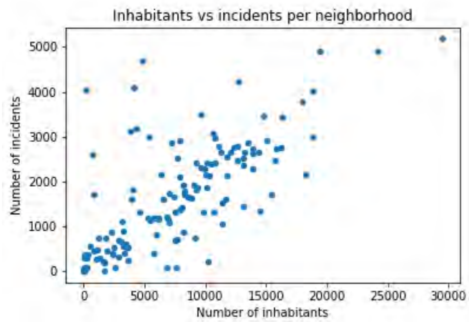


Fig:A   Fig:B

Figure 4.2: Geographical incident information. Figure A shows the incidents per neighbourhood and figure B the ratio between incidents and inhabitants per neighbourhood.

4.2 Response time

This section will give some information on the response time of the FDAA. The response time is divided into three components. The first part is the notification time. This is the time between the incident call to the control room and from there the notification to the FDAA (or any other fire brigade). This is followed by the pre-trip delay of the FDAA. Full timers have an average pre-trip delay of 90 seconds whereas part-timers need 180 seconds. This is because the part-timers first need to travel to the barracks. The last component is the travel time. The incidents are divided into three priority levels, where 1 is the highest priority, and therefore, requires the quickest response from the FDAA. Table 4.2 shows the average response time per priority. Nowadays, priority 3 is removed and only 1 and 2 are possible. The fact that the average response time for priority 3 is slightly lower than priority 2 is surprising, but not necessarily a problem. The important fact is that on average a priority 1 response is around 160 seconds faster than for a priority 2 incident.

Priority	Average response time in (s)	Number of incidents
1	493	118,146
2	651	41,739
3	650	10,137

Table 4.2: Number of incidents per priority and the average response time per priority

Next up, the response time per incident type will be given. This is important because every incident type has its own target response time by law. Table 4.3 shows these response times. The first thing to notice is the high response time for "Regionale bijstand". These are incidents outside the safety region of the FDAA and therefore understandably long. Let us look at the average response time for every barrack. As stated before, the FDAA has currently 18 barracks, each of which have different teams and vehicles to its disposal. Most barracks have an average response time between 375 and 500 seconds (± 6 to 9 minutes). The barracks who stand out are "AALSMEER", "UITHOORN" and "DRIEMOND". The slower response times for these barracks are explained due to the fact that only part-timers work at these barracks and therefore naturally have a longer turn-out time, because they first have to travel to the barracks. Chapter 1 contains information about the way part-timers work for the FDAA.

Incident type	Response time	Incident type	Response time
(Inter)Regionale bijstand	1,994	Hulpverlening water algemeen	828
Afhijsen	493	Letsel eigen personeel	910
Assistentie Ambulance	558	Liftopsluiting	564
Assistentie Politie	485	Loos Alarm	519
Automatisch of optisch alarm	456	Meten / overlast / verontreiniging	470
Beknelling / bevrijding	564	Nacontrole	532
Binnenbrand	543	OMS melding	431
Brandbare gassen	467	Oefening of test	351
Brandgerucht	451	Overig brand	385
Buitenbrand	576	Overige gevaarlijke stoffen	633
Buitensluiting	581	Overige hulpverlerning	601
Dier te water	848	PAC melding	463
Extreem weer	674	Persoon te water	532
Hulpverlening Dieren	762	Reanimeren	458
Hulpverlening Luchtvaart	394	Uitval systeem of voorziening	922
Hulpverlening algemeen	581	Voertuig te water	693

Table 4.3: Average response time (in seconds) per incident type (in Dutch) not filtered on priority

Barrack	Response time	Barrack	Response time
AALSMEER	691	IJSBRAND	559
AMSTELVEEN	592	NICO	525
ANTON	532	OSDORP	534
DIEMEN	592	PIETER	505
DIRK	522	TEUNIS	548
DRIEMOND	900	UITHOORN	659
DUIVENDRECHT	568	VICTOR	500
GBA	494	WILLEM	591
HENDRIK	465	ZEBRA	532

Table 4.4: Average response time (in seconds) per barrack not filtered on priority

4.3 Volunteer distribution

Via the algorithm in section 3.3 an optimal volunteer distribution is calculated. This distribution can be found in Appendix A. The value of this optimization algorithm is tested by comparing the results obtained by the optimal volunteer distribution with a distribution that is proportional to the number of inhabitants of that region. This proportional volunteer distribution can be found in Appendix B.

Chapter 5

Results

In this chapter the results will be presented. Chapter 3 describes the different scenarios that will be tested. Two different results will be shown per scenario. First, one using the volunteer distribution optimized by the algorithm explained in section 3.3 and one using a volunteer distribution that is proportional to the number of inhabitants per region. The aggregation level chosen is "neighbourhood" (Dutch = "wijk"). The volunteer distributions for the aggregation level can be found in Appendix A and B. In total 139,680 incidents were simulated over a period of three years. Every scenario responds to the same incidents, which makes the results comparable.

5.1 The response time of the FDAA

The first result is the response time of the FDAA on the simulated incidents, figure 5.1. The largest response time, which is for the area located top-left ("Westelijk Havengebied"), is explained by the fact that the simulator chooses the closest barrack to respond to an incident and it can happen that the GBA barrack, which is located in the far top left, is further away from an incident in "Westelijk Havengebied" than a barrack in the centre of the safety-region. This makes it plausible that some high response times are generated. On average the response times are 551 seconds (±

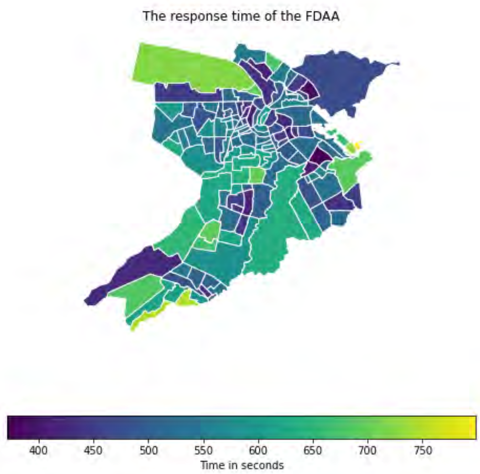


Figure 5.1: The average response time of the FDAA for simulated incidents per region

9 minutes). This is 10 seconds slower than the incident data showed in the period from 2008 until 2021. This has to be taken into account when comparing results. Another interesting observation is that the areas located in the bottom of the safety region have a slower response time (on average) but one area is performing well, which is "Aalsmeer". This is due to the fact that most of this area consists of water and most incidents are in the Northern part of this region which is exactly where this barrack is located.

5.2 Scenario 1: Ideal situation

This section is devoted to the ideal scenario. Table 3.2 shows the variables of this situation. The most important fact is that the FDAA have 100,000 volunteers in this example, which is the goal given by the Commander for the Year 2030. Figures 5.2 and 5.3 give a clear insight that the

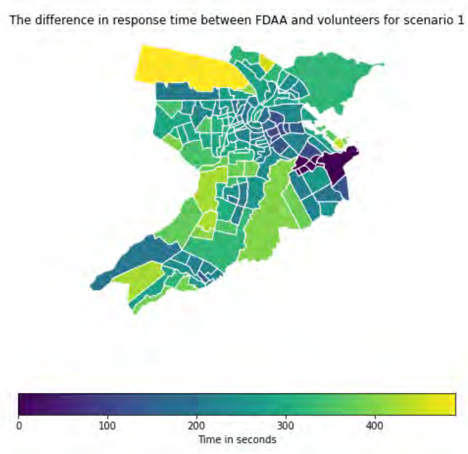


Figure 5.2: Scenario1: Optimal

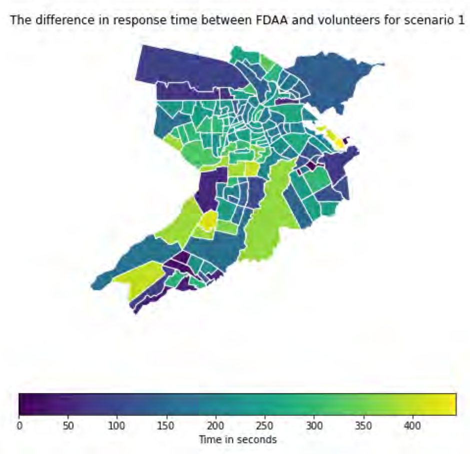


Figure 5.3: Scenario1: Proportional

optimal volunteer distribution works better than the proportional volunteer distribution. Figure 5.2 shows that almost all regions benefit from having volunteers responding, whereas figure 5.3 contains some areas where the gain is not as much. The average response time for the optimal volunteer distribution is 254 seconds faster than the FDAA where the proportional distribution is 209 seconds faster.

5.3 Scenario 2: Half of the desired volunteers

The main difference between scenarios 1 and 2 is that the setting in scenario 2 only has 50.000 volunteers, which is half of scenario 1. This scenario will be used to test if the 100.000 volunteer goal set by the commander is essential or not. Comparing the results of figures 5.4 and 5.5 it is clear that the optimal volunteer distribution has a better response time than the proportional distribution. On average it is 220 seconds faster in comparison to the FDAA. The proportional distribution is on average 175 seconds faster. Notice that the optimal volunteer distribution in scenario 2 has a faster response time than the proportional distribution in scenario 1.

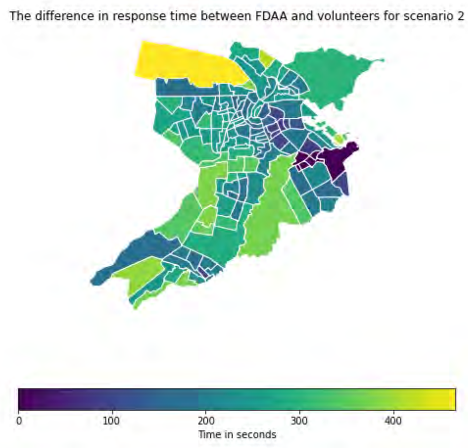


Figure 5.4: Scenario 2: Optimal

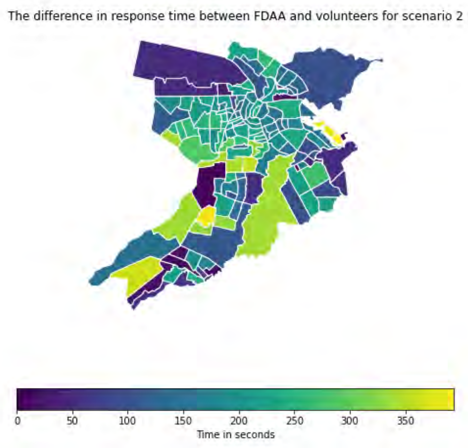


Figure 5.5: Scenario 2: Proportional

5.4 Scenario 3: A tenth of the desired volunteers

This scenario is the most pessimistic in view of the total number of volunteers. During this scenario, only 10,000 volunteers are available. The legends of figures 5.6 and 5.7 both have a smaller range of values in comparison to scenarios 1 and 2. This means that in this scenario the gain in response time is far less. Still, both scenarios are faster than the FDAA. The response time of the optimal volunteer distribution is on average 120 seconds faster than that of the FDAA, which is still 2 minutes. The proportional distribution is 92 seconds faster than the FDAA. Some regions are doing well, but in others the gain is 0 seconds. Therefore, on average the result seems decent, but on a regional level the impact is not that great. With scenarios 1, 2 and 3 covered the

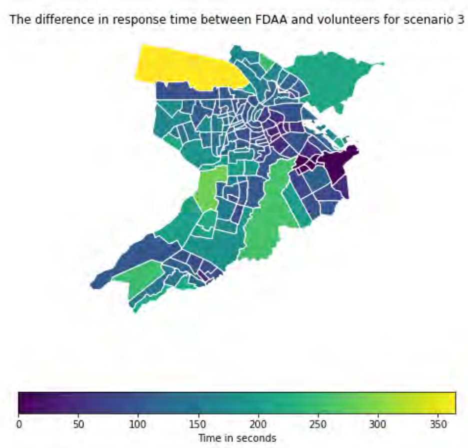


Figure 5.6: Scenario 3: Optimal

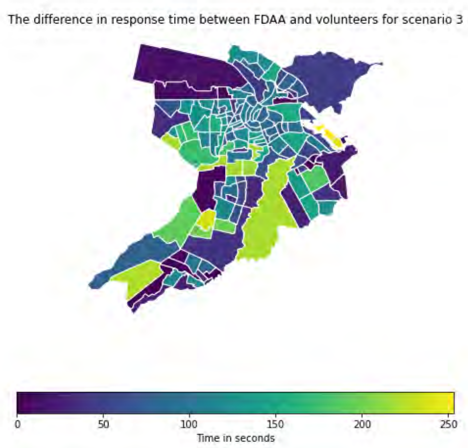


Figure 5.7: Scenario 3: Proportional

results for the variability in total available volunteers are done.

5.5 Scenario 4: Half of the expected acceptance rate

This section in combination with scenario 5 is intended to test the effect of variability in acceptance rate. As noted in chapter 3 the acceptance rate is the chance a volunteer is available to accept a call to respond to an incident. This scenario will mainly be compared to scenario 1, because this scenario will still have the goal of 100,000 volunteers, but the acceptance rate is half in comparison to scenario 1. Figures 5.8 and 5.9 show that both distributions are still lowering the response time. The average response time of the optimal volunteer distribution is 219 seconds and that of the proportional is 175 seconds. This shows that even if the acceptance rate is halved, the response times are much faster than the FDAA. Moreover, in comparison to scenario 1, the difference is around 30 seconds.

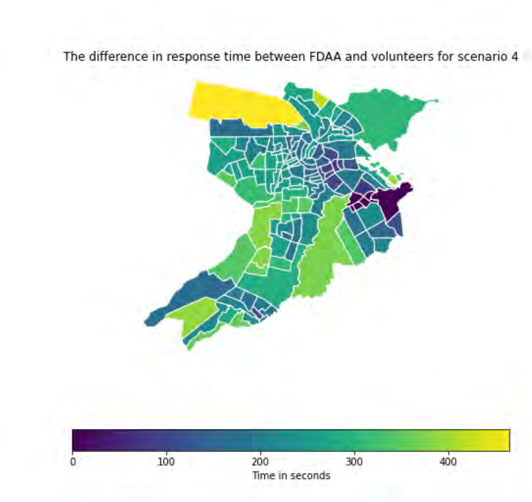


Figure 5.8: Scenario 4: Optimal

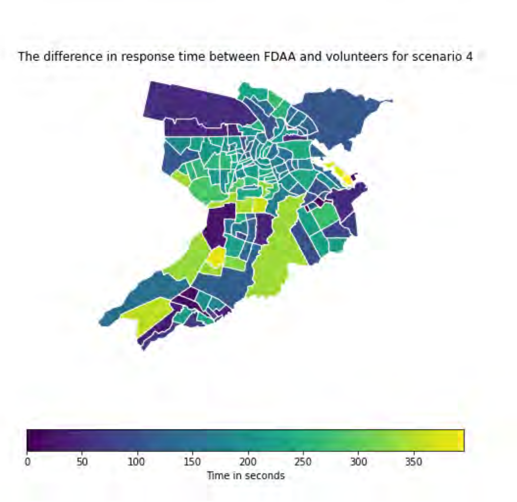


Figure 5.9: Scenario 4: Proportional

5.6 Scenario 5: A tenth of expected volunteer rate

Next up, the acceptance rate is even smaller than before. It is now a tenth of the acceptance rate in scenario 1. Figures 5.10 and 5.11 show that the response times are still very positive in comparison to the FDAA. The optimal distribution has on average a quicker response time of 119 seconds and the proportional one is 92 seconds faster. This is still considerably quicker than the FDAA. However, it is a lot slower in comparison to scenario 4.

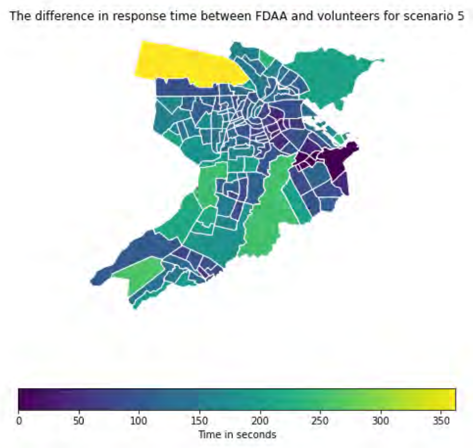


Figure 5.10: Scenario 5: Optimal

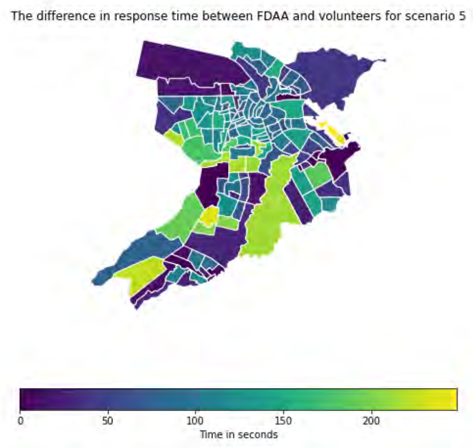


Figure 5.11: Scenario 5: Proportional

5.7 Scenario 6: Dutch people cycle

The following scenario is quite interesting for the Netherlands, as volunteers will move at a faster pace in comparison to standard modelling. This is due to the fact that it is possible for a volunteer

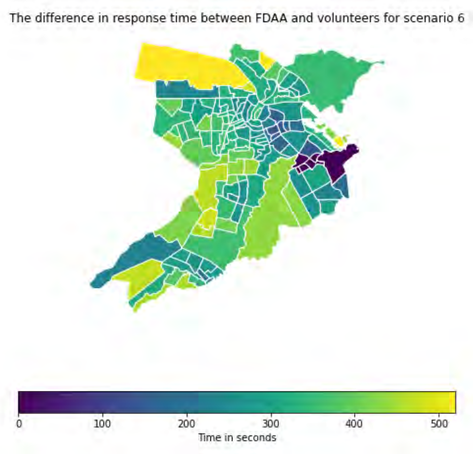


Figure 5.12: Scenario 6: Optimal

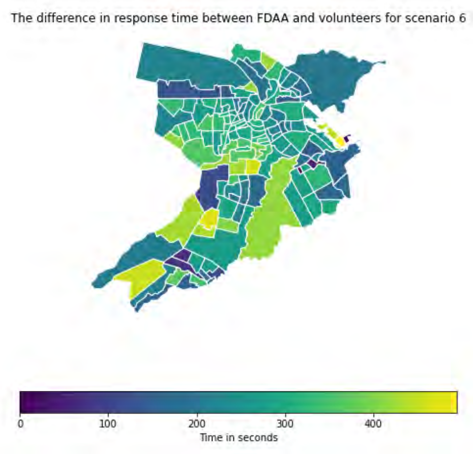


Figure 5.13: Scenario 6: Proportional

to use its bike to travel. This scenario is quite plausible as the Dutch population owns 22.8 million bikes, whereas the Netherlands only has 17.4 million inhabitants. This gives us the ability to set the pace of the volunteers to 12km/hr. Therefore, the region surrounding an incident where a volunteer can still reach the incident in time is drastically larger. Figures 5.12 and 5.13 show, as expected, that the response time is vastly improved in comparison to that of the FDAA. Indeed, the optimal solution improves the FDAA's response time on average with 302 seconds, whereas the proportional distribution improves it by 265 seconds. The result shows that an improvement of the response time is established for all regions which do not have a barrack. Moreover, the response time is around one minute faster in comparison to that of scenario 1.

5.8 Scenario 7: A longer pre-trip delay

An important step in the whole process of volunteers aiding the FDAA is the pre-trip delay. Chapter 2 already introduced the term pre-trip delay and, in short, it involves the time for the FDAA/Emergency centre to call the volunteer in addition to the time it takes to get ready. Scenario 1 had a pre-trip delay of 3 minutes and scenarios 7 and 8 are testing the effect on the response time when the pre-trip delay changes. First a longer pre-trip is tested. Figures 5.14 and

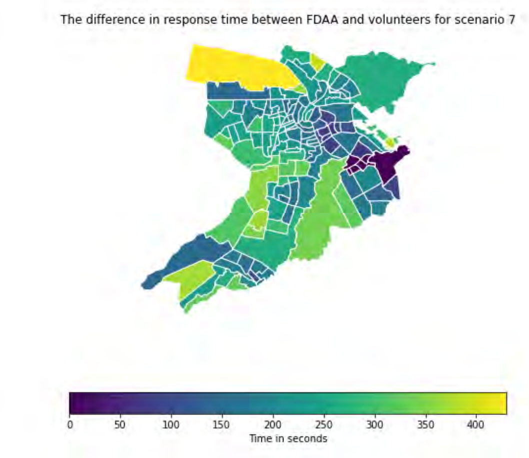


Figure 5.14: Scenario 7: Optimal

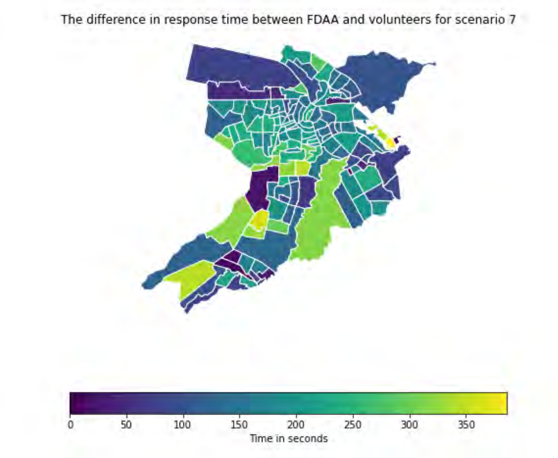


Figure 5.15: Scenario 7: Proportional

5.15 show the results of these longer pre-trip delays. Both still improve on the response time of the FDAA, with improvements of 205 and 166 seconds, respectively. Notice that these results are comparable to scenario 2 which had 50,000 fewer volunteers than this scenario, but a shorter pre-trip delay.

5.9 Scenario 8: A shorter pre-trip delay

The last scenario is devoted to see the results of the pre-trip delay is lowered to two minutes instead of three. The results are shown in figures 5.16 and 5.17. As expected, both distributions outperform scenario 1 significantly with response times that are 308 and 259 seconds faster than those of the FDAA, respectively. The response times are, as expected, around 60 seconds faster than scenario 1. This gain in response time is exactly the difference in pre-trip delay.

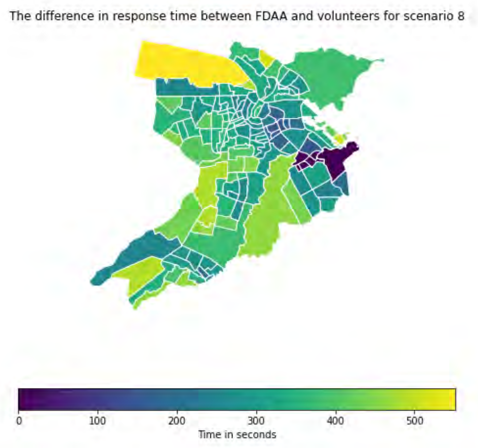


Figure 5.16: Scenario 8: Optimal

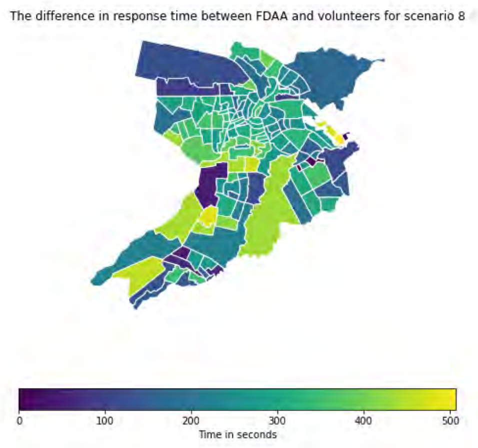


Figure 5.17: Scenario 8: Proportional

5.10 Overview

For every scenario, the optimal volunteer distribution outperformed the proportional volunteer distribution. The following box plots give an overview of the simulated scenarios. Figure 5.18 shows that most outliers are on the positive side of the median. A few values are 0 in every scenario; this means having volunteers was not helpful for every neighbourhood in improving the response time of the FDAA. What is nice to see is that the interquartile range (IQR) is around 60 seconds for every scenario and very consistent. Scenarios 6 and 8 are very similar, which shows that having a pre-trip delay of two minutes has almost the same effect as volunteers moving by bike. Both respond on average one minute faster than scenario 1. For convenience, the different scenarios are again displayed in table 5.1.

	Variables			
Scenario	n	α	w	τ_v
1	100,000	0.1	0.1	3
2	50,000	0.1	0.1	3
3	10,000	0.1	0.1	3
4	100,000	0.05	0.1	3
5	100,000	0.01	0.1	3
6	100,000	0.1	0.2	3
7	100,000	0.1	0.1	4
8	100,000	0.1	0.1	2

Table 5.1: Different scenarios to simulate

Figure 5.19 shows a similar pattern as figure 5.18, but the IQR is bigger. Also noteworthy is the fewer number of outliers north of the IQR.

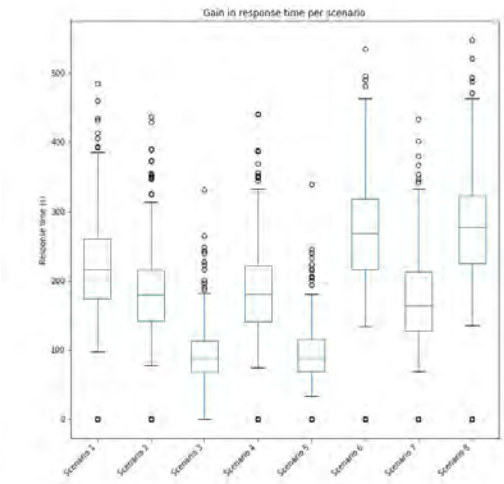


Figure 5.18: Overview of response time with optimal volunteer distribution

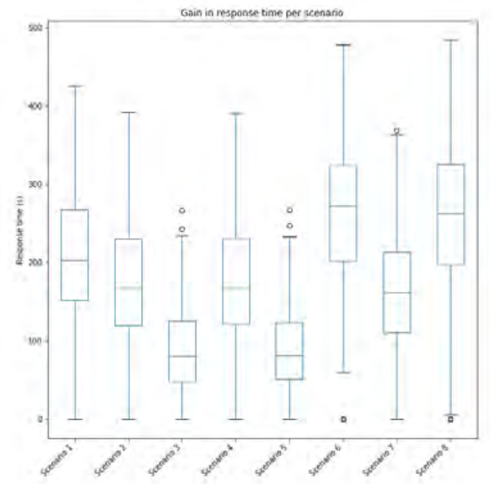


Figure 5.19: Overview of response time with proportional distribution

Chapter 6

Conclusions

This chapter will focus on answering the research question stated in chapter 1 using the results of chapter 5. This paper was written to answer the following question:

> *What will the impact be on the response time if volunteers are responding to incidents as well?*

This question was answered by using methods stated in chapter 3. The implementation of a Poisson point process was very helpful for modelling the volunteers around an incident. Using theory from the ambulance sector and implementing it for the FDAA turned out to be a great find. The combination with the algorithm used to optimize the allocation of volunteers around the city provided a suitable model to calculate the response times of volunteers. This made it possible to compare the results between the volunteers and the FDAA for 8 different scenarios.

Looking at the results of chapter 5, it is clear that using volunteers improves the response time of the FDAA. Every scenario had a better average response time than the FDAA. This clearly shows that, whatever the setting, volunteers will improve the response time.

To reach this faster response time, a few components need to be taken into account. First, the commander of the FDAA desired 100,000 volunteers, but as shown in chapter 5 the results with even 50,000 volunteers are very promising. The number of 100,000 was of course an estimate by the Commander, but this research shows that a number of 50,000 would be a good target to achieve. This could improve the average response time by 220 seconds, which is almost 4 minutes! Having the additional 50,000 volunteers would improve the response time by another 30 seconds.

Secondly, the impact of the acceptance rate was not incredibly significant. The results show that halving the acceptance rate has around the same result as halving the total number of volunteers. This is expected as the equation $u = nav$ multiplies the total number of volunteers with the acceptance rate. Hence, the response times will be similar, when these variables balance themselves out.

Another insight is that letting the volunteers move by bike has around the same influence as having a shorter pre-trip delay of one minute. Therefore, when volunteers move by bike, one minute will be gained on average.

Furthermore, in every single scenario, the average response time was better when the optimization algorithm by van den Berg et al. [2021] was used for the volunteer distribution instead of the proportional distribution. On average the response times are around 30 seconds quicker for the optimized distribution, but the most important observation is that all regions have improvements in response times, whereas the proportional volunteer distribution has some regions where there is no improvement.

The simulator created by van den Bogaert [2019] had response times of the FDAA which were slightly higher than the average response times of the FDAA on incidents in the period 2008-2021. Therefore, this difference has to be taken into account when comparing the results.

Also, the aggregation level for this research was the neighbourhood level (”Wijk” in Dutch) and had good results. If the aggregation level was even finer, district (”Buurt” in Dutch), then the areas would be so small that the greedy algorithm didn’t perform well as some regions would have no allocated volunteer mass. By taking a larger aggregation level like suburb (”Stadsdeel” in Dutch), the assumption that the volunteers are evenly distributed over this area seems a bit far-fetched. This would result in not being able to use a Poisson point process to calculate the response time distribution for volunteers surrounding an incident.

Big areas like ”Westelijk Havengebied” and ”Aalsmeer” are receiving the largest values from the distribution. This is logical because these areas are so large and the volunteers need to be spread out to have an impact. On the other hand, the smaller areas do not need to spread out the volunteers, even when this area has a lot of incidents. To wrap up, by using the simulator of the FDAA and combining this with the methods in chapter 3 it is possible for the FDAA to simulate unlimited scenarios and test whether the impact of volunteers is large enough to be implemented. From the scenarios discussed, the impact looks promising and should help the FDAA in reducing their response time as well as finding an optimal allocation for the volunteers.

Chapter 7

Recommendations and Further Research

7.1 Recommendations

The results clearly show that volunteers will improve the response time. Therefore, the advice is that the rough target from the commander of the FDAA should be changed to a real operational target for 2030.

The number of volunteers is a very important topic. Bearing in mind the results of chapter 5, a target of 50,000 should generate very positive results. The acceptance rate is a bit trickier, because it is not in the hands of the FDAA. The best way to find this value is by putting the project in practice and see how willing volunteers are to react to an incident. The estimate of 0.1 is a good starting point as Wikipedia [2021] shows that people in the Netherlands are very willing to help.

The volunteer distribution calculated by the algorithm shown in chapter 3 should be used to find the optimal allocation of the volunteers. This is done by multiplying the total number of volunteers that the FDAA has to their disposal with the value found in Appendix A. This gives a number of volunteers for every neighbourhood. Of course, in the beginning of recruiting volunteers the rule "more=better" should be followed, but in later stages the location of the volunteers should be a priority to the recruiters.

7.2 Further research

This research did not touch on what volunteers can do at an incident location. It is not unimaginable that volunteers go to an incident location with a fire extinguisher (or other equipment). As a result it would be interesting to see what happens if the volunteers have to take an extra stop. The result would be that the process of a volunteer would be 1) accepting a call, 2) move to a location which has equipment, and 3) move to an incident location. This operation would be possible with equipment available and deployed all over the city in public locations. For this to happen the FDAA needs to decide for which incident types they wish to deploy volunteers and what the desired actions at an incident location are for a volunteer.

In comparison to 2019 when the simulator was created the FDAA switched to a new type of data storage. During this process, the input data no longer has an object input. What this means is that when an incident happens in or near a building, the FDAA retrieves the info on this building. For example, schools or retirement homes. The different types would also give distinct target response times. With this data missing, conclusions on the percentage of arrivals within the target time were not possible to give, while this is an interesting metric.

Another interesting topic is the area surrounding an incident. During this research, an assumption is made that the volunteers can travel to an incident if they are within a circle of the incident. The area of this circle depends on the speed a volunteer can travel, but this assumption uses the fact that volunteers would be able to move directly to an incident, whereas in practice it wouldn't be possible to move straight to an incident location.

Lastly, large areas require a lot of volunteer mass when using the optimal volunteer distribution, but it is not obvious that having this many volunteers in these areas is possible. Therefore, this aspect needs to be investigated as well.

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Appendix A

Optimal volunteer distribution

In the first appendix the volunteer distribution is given which is calculated by an (greedy) optimization algorithm. This volunteer distribution is tested in simulation versus the volunteer distribution given in Appendix B. The values shown sum up to 1. These values need to be multiplied with the total number of available volunteers to obtain the desired number of volunteers per region.

Wijk Omschrijving	Volunteer distribution
Wijk 00 Aalsmeer	0.0155
Wijk 01 Kudelstraat en Kalslagen	0.0115
Wijk 02 Oosteinde	0.0125
Randwijck	0.0065
Patrimonium	0.0065
Elsrijk	0.0075
Stadshart	0.0069
Uilenstede, Kronenburg	0.0065
Bankras, Kostverloren	0.0075
Buitengebied Noord	0.0085
Keizer Karelpark	0.0082
Groenelaan	0.0075
Waardhuizen, Middenhoven	0.0075
Bovenkerk - Westwijk Noord	0.0075
Westwijk Zuid	0.0077
Buitengebied Zuid	0.0155
Amsterdamse Bos	0.0115
Burgwallen-Oude Zijde	0.0065
Burgwallen-Nieuwe Zijde	0.0062
Grachtengordel-West	0.0065
Grachtengordel-Zuid	0.0065
Nieuwmarkt/Lastage	0.0065
Haarlemmerbuurt	0.0062
Jordaan	0.0065
De Weteringschans	0.0065
Weesperbuurt/Plantage	0.0065
Oostelijke Eilanden/Kadijken	0.0075
Westelijk Havengebied	0.0255
Bedrijventerrein Sloterdijk	0.0115
Houthavens	0.0065
Spaarndammer- en Zeeheldenbuurt	0.0075
Staatsliedenbuurt	0.0065

Centrale Markt	0.0065
Frederik Hendrikbuurt	0.0065
Da Costabuurt	0.0058
Kinkerbuurt	0.0065
Van Lennepbuurt	0.0065
Helmersbuurt	0.0065
Overtoomse Sluis	0.0058
Vondelbuurt	0.0065
Zuidas	0.0075
Oude Pijp	0.0065
Nieuwe Pijp	0.0060
Zuid Pijp	0.0065
Weesperzijde	0.0065
Oosterparkbuurt	0.0065
Dapperbuurt	0.0060
Transvaalbuurt	0.0065
Indische Buurt West	0.0065
Indische Buurt Oost	0.0075
Oostelijk Havengebied	0.0088
Zeeburgereiland/Nieuwe Diep	0.0085
IJburg West	0.0065
Sloterdijk	0.0065
Landlust	0.0064
Erasmuspark	0.0065
De Kolenkit	0.0065
Geuzenbuurt	0.0065
Van Galenbuurt	0.0058
Hoofdweg e.o.	0.0065
Westindische Buurt	0.0065
Hoofddorppleinbuurt	0.0065
Schinkelbuurt	0.0058
Willemspark	0.0065
Museumkwartier	0.0075
Stadionbuurt	0.0065
Apollobuurt	0.0071
IJburg Oost	0.0065
IJburg Zuid	0.0065
Scheldebuurt	0.0065
IJselbuurt	0.0058
Rijnbuurt	0.0065
Frankendael	0.0075
Middenmeer	0.0085
Betondorp	0.0073
Omval/Overamstel	0.0085
Prinses Irenebuurt e.o.	0.0065
Volewijck	0.0075
IJplein/Vogelbuurt	0.0075
Tuindorp Nieuwendam	0.0065
Tuindorp Buiksloot	0.0065
Nieuwendammerdijk/Buiksloterdijk	0.0065
Tuindorp Oostzaan	0.0075
Oostzanerwerf	0.0085
Kadoelen	0.0075
Waterlandpleinbuurt	0.0075

Buikslotermeer	0.0075
Banne Buiksloot	0.0075
Noordelijke IJ-oevers West	0.0085
Noordelijke IJ-oevers Oost	0.0065
Waterland	0.0231
Elzenhagen	0.0065
Chass©buurt	0.0065
Slotermeer-Noordoost	0.0065
Slotermeer-Zuidwest	0.0083
Geuzenveld	0.0075
Eendracht	0.0075
Lutkemeer/Ookmeer	0.0095
Osdorp-Oost	0.0078
Osdorp-Midden	0.0065
De Punt	0.0065
Middelveldsche Akerpolder	0.0075
Slotervaart Noord	0.0075
Overtoomse Veld	0.0075
Westlandgracht	0.0075
Sloter-/Riekerpolder	0.0105
Slotervaart Zuid	0.0075
Buitenveldert-West	0.0085
Buitenveldert-Oost	0.0075
Amstel III/Bullewijk	0.0095
Bijlmer Centrum (D,F,H)	0.0084
Bijlmer Oost (E,G,K)	0.0095
Nellestein	0.0085
Holendrecht/Reigersbos	0.0085
Gein	0.0076
Driemond	0.0075
Diemen Noord	0.0075
Diemen Centrum	0.0073
Wijk 00	0.0185
Wijk 15 Dorpscentrum	0.0065
Wijk 25 Thamerdal	0.0060
Wijk 35 Zijdelwaard	0.0065
Wijk 45 Legmeer	0.0075
Wijk 50 Langs de Vuurlinie	0.0075
Wijk 55 Veilinggebied	0.0073
Wijk 65 Meerwijk	0.0065
Wijk 75 Bedrijventerrein	0.0065
Wijk 85 Meerwijk	0.0065
Wijk 90 Glastuinbouwgebied	0.0080
Wijk 95 Veenweidegebied	0.0075
Diemen Zuid	0.0000
Bergwijkpark	0.0000
Holland Park	0.0000
Bedrijventerreinen	0.0000
Plantage de Sniep	0.0000
Buitengebied	0.0000

Appendix B

Proportional volunteer distribution

This appendix shows the volunteer distribution with a proportional rate to the inhabitants. This is used as a baseline model in comparison to the optimal volunteer distribution shown in Appendix A. The values below sum up to 1. These values need to be multiplied with the total number of available volunteers to obtain the desired number of volunteers per region.

Wijk Omschrijving	Volunteer Distribution
Wijk 00 Aalsmeer	0.0119
Wijk 01 Kudelstraat en Kalslagen	0.0086
Wijk 02 Oosteinde	0.0093
Randwijck	0.0056
Patrimonium	0.0029
Elsrijk	0.0107
Stadshart	0.0029
Uilenstede, Kronenburg	0.0033
Bankras, Kostverloren	0.0093
Buitengebied Noord	0.0007
Keizer Karelpark	0.0114
Groenelaan	0.0074
Waardhuizen, Middenhoven	0.0124
Bovenkerk - Westwijk Noord	0.0101
Westwijk Zuid	0.0072
Buitengebied Zuid	0.0011
Amsterdamse Bos	0.0001
Burgwallen-Oude Zijde	0.0040
Burgwallen-Nieuwe Zijde	0.0038
Grachtengordel-West	0.0060
Grachtengordel-Zuid	0.0050
Nieuwmarkt/Lastage	0.0091
Haarlemmerbuurt	0.0088
Jordaan	0.0183
De Weteringschans	0.0068
Weesperbuurt/Plantage	0.0073
Oostelijke Eilanden/Kadijken	0.0125
Westelijk Havengebied	0.0001
Bedrijventerrein Sloterdijk	0.0008
Houthavens	0.0022
Spaarndammer- en Zeeheldenbuurt	0.0101

Staatsliedenbuurt	0.0124
Centrale Markt	0.0023
Frederik Hendrikbuurt	0.0078
Da Costabuurt	0.0043
Kinkerbuurt	0.0061
Van Lennepbuurt	0.0066
Helmersbuurt	0.0070
Overtoomse Sluis	0.0074
Vondelbuurt	0.0017
Zuidas	0.0036
Oude Pijp	0.0139
Nieuwe Pijp	0.0117
Zuid Pijp	0.0077
Weesperzijde	0.0055
Oosterparkbuurt	0.0102
Dapperbuurt	0.0096
Transvaalbuurt	0.0087
Indische Buurt West	0.0119
Indische Buurt Oost	0.0095
Oostelijk Havengebied	0.0178
Zeeburgereiland/Nieuwe Diep	0.0034
IJburg West	0.0146
Sloterdijk	0.0005
Landlust	0.0178
Erasmuspark	0.0055
De Kolenkit	0.0096
Geuzenbuurt	0.0064
Van Galenbuurt	0.0071
Hoofdweg e.o.	0.0097
Westindische Buurt	0.0065
Hoofddorppleinbuurt	0.0111
Schinkelbuurt	0.0037
Willemspark	0.0051
Museumkwartier	0.0120
Stadionbuurt	0.0111
Apollobuurt	0.0081
IJburg Oost	0.0000
IJburg Zuid	0.0078
Scheldebuurt	0.0142
IJselbuurt	0.0050
Rijnbuurt	0.0086
Frankendael	0.0106
Middenmeer	0.0150
Betondorp	0.0030
Omval/Overamstel	0.0045
Prinses Irenebuurt e.o.	0.0012
Volewijck	0.0091
IJplein/Vogelbuurt	0.0078
Tuindorp Nieuwendam	0.0033
Tuindorp Buiksloot	0.0017
Nieuwendammerdijk/Buiksloterdijk	0.0015
Tuindorp Oostzaan	0.0110
Oostzanerwerf	0.0084
Kadoelen	0.0031

Waterlandpleinbuurt	0.0124
Buikslotermeer	0.0105
Banne Buiksloot	0.0136
Noordelijke IJ-oevers West	0.0038
Noordelijke IJ-oevers Oost	0.0003
Waterland	0.0021
Elzenhagen	0.0026
Chass buurt	0.0058
Slotermeer-Noordoost	0.0088
Slotermeer-Zuidwest	0.0169
Geuzenveld	0.0153
Eendracht	0.0023
Lutkemeer/Ookmeer	0.0010
Osdorp-Oost	0.0154
Osdorp-Midden	0.0148
De Punt	0.0057
Middelveldsche Akerpolder	0.0137
Slotervaart Noord	0.0076
Overtoomse Veld	0.0131
Westlandgracht	0.0100
Sloter-/Riekerpolder	0.0132
Slotervaart Zuid	0.0100
Buitenveldert-West	0.0127
Buitenveldert-Oost	0.0074
Amstel III/Bullewijk	0.0006
Bijlmer Centrum (D,F,H)	0.0228
Bijlmer Oost (E,G,K)	0.0278
Nellestein	0.0027
Holendrecht/Reigersbos	0.0172
Gein	0.0108
Driemond	0.0015
Diemen Noord	0.0064
Diemen Centrum	0.0096
Wijk 00	0.0131
Wijk 15 Dorpscentrum	0.0009
Wijk 25 Thamerdal	0.0031
Wijk 35 Zijdelwaard	0.0066
Wijk 45 Legmeer	0.0071
Wijk 50 Langs de Vuurlinie	0.0002
Wijk 55 Veilinggebied	8.98e-05
Wijk 65 Meerwijk	0.0054
Wijk 75 Bedrijventerrein	0.0002
Wijk 85 Meerwijk	0.0034
Wijk 90 Glastuinbouwgebied	0.0002
Wijk 95 Veenweidegebied	9.45e-05
Diemen Zuid	0.0071
Bergwijkpark	0.0000
Holland Park	0.0024
Bedrijventerreinen	5.20e-05
Plantage de Sniep	0.0015
Buitengebied	0.0001