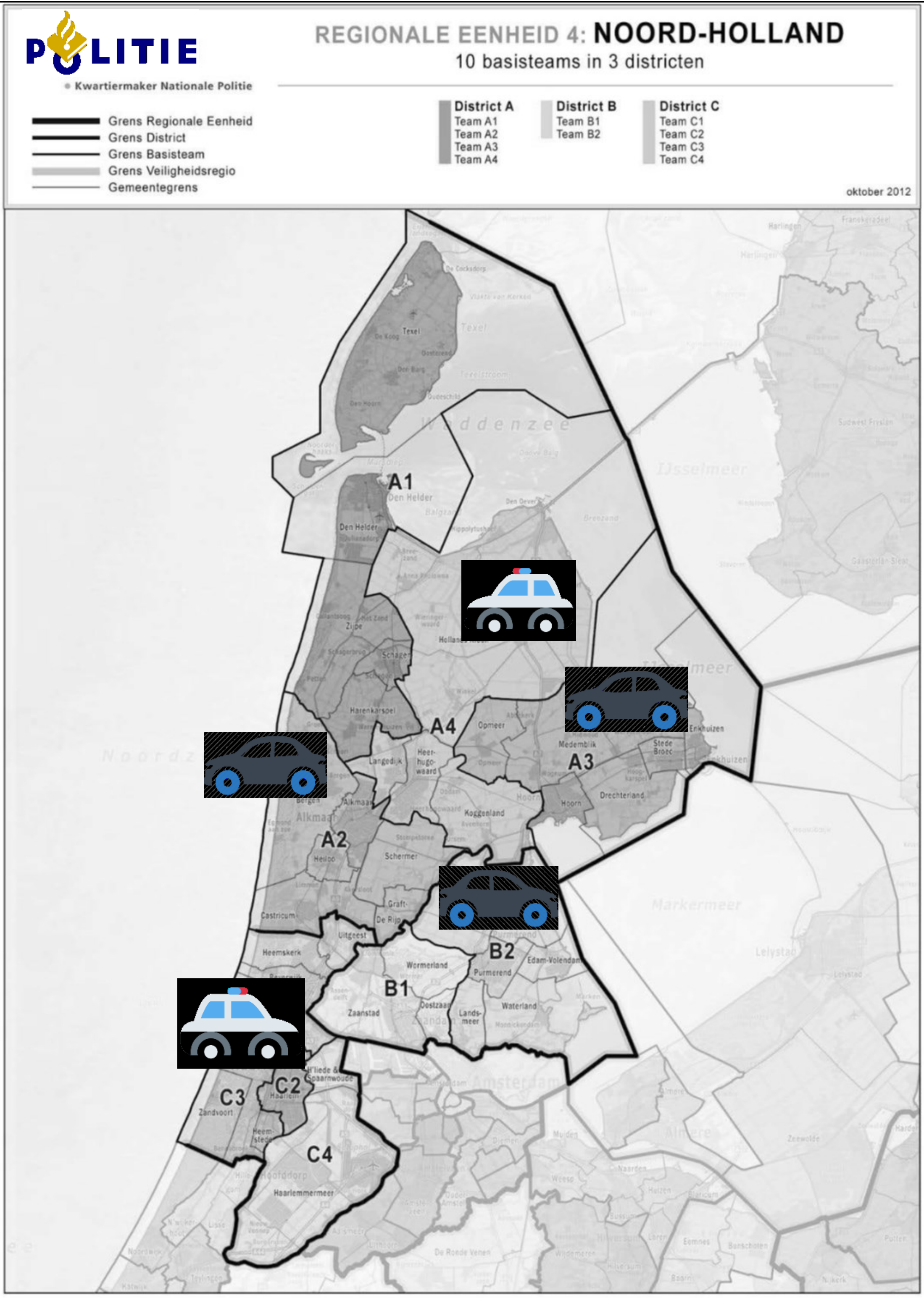
Distributing Police Vehicles Across Noord-Holland



Distributing emergency and civilian vehicles to maximize the mobility

T. Hoek

Table of Contents

List of Abbreviations

Abbreviation	Expanded
AVIM	Afdeling Vreemdelingenpolitie, Identificatie & Mensenhandel
BACOP	Backup Coverage Problem
BT	Base Team
DR	Districts Recherche
DROC	Dienst Regionaal Operationeel Centrum
DSM	Double Standard Model
FCFS	First Come, First Serve
FTE	Full-time Equivalent
HIC	High Impact Crime
KEN	Kennemerland
KPI	Key Performance Indicators
LSCP	Location Set Covering Problem
MCLP	Maximal Covering Location Problem
mDSM	multi-period Double Standard Model
MEXCLP	Maximum Expected Coverage Location Problem
MRMCLP	Multi-Response Maximal Covering Location Problem
NHN	Noord Holland-Noord
OpCo	Operational Coordinator
OVDP	Officier Van Dienst - Politie
PDC	Politie Diensten Centrum
RSC	Regionaal Service Centrum
RTIC	Real-Time Intelligence Centre
SVP	Strategic Vehicle Plan
SVS	Shared Vehicle System
TIMEXCLP	Time-dependent Maximum Expected Coverage Location Problem
Unit	Unit of Noord Holland
WOB	Wet Openbaarheid Bestuur
ZAW	Zaanstreek Waterland

List of Tables

List of Figures

Preface

This research concerns the (re)distribution of vehicles for the Unit of Noord Holland. It is a combination of what I like to do, optimization, and what has been and still is a big part of my dad's life, the Police. It is thanks to his connections that I could perform this research at the Unit. It is a great experience to get to know my own foundations a bit better.

Guiding me through the Unit, Kim and Serge have helped me greatly with achieving the outcome you can see before you. To get to it has been kind of personal struggle, ranging from being too positive about finishing parts of the research, to being unable to see the end and feeling ashamed about not doing the things I should. Suffice to say, getting to the end and writing this preface lifts a huge weight from my shoulder, something that I will enjoy very much. It is a strange thing that one can feel paralyzed because of shame, when just doing anything will lift the shame and paralysis. It is with many great thanks to Kim, Serge, my parents and siblings, friends, Peter, Martijn and the Unit of Noord Holland that I can finish this part of my life.

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POLITIE

Management Summary

This research considers the distribution of emergency and civilian vehicles for the Unit of Noord Holland. The Unit is reorganising the teams, the offices and as a result, also it's vehicles. The vehicles are tools to provide mobility to the Unit. This leads to the following research question:

> *How should the Unit of Noord-Holland redistribute its vehicles across Noord-Holland, to maximize its mobility?*

Two types of vehicles are considered in this research: Emergency and Civilian. Within the current fleet, four vehicle categories have been defined: Civilian, Striped, Specialized and Covert vehicles. The striped vehicles have been categorized further into seven subcategories, one of which containing the Emergency vehicles. The other vehicles are not considered, covert vehicles have to remain covert, specialized vehicles are dedicated to specialised tasks, fixing the distribution decision, and the six other subcategories are also dedicated to specialised tasks.

Maximising the mobility for emergency vehicles means maximizing the percentage of handling incidents in-time. Within 15 minutes for priority 1 and 30 minutes for priority two, while also handling priority three incidents. Maximising the mobility for civilian vehicles means minimising the probability of having to wait for a vehicle, for all teams equally. The Unit wants to gain insight on the effects of vehicle pooling, assign vehicle to teams or pool vehicles at offices, and on the effects of having dedicated vehicles for standby-services or not.

Emergency vehicles
For emergency vehicles, a distribution model, based on Daskin's MEXCLP[1], is used allocating all vehicles (125 for 10 Base Teams) to a node. The area of the Unit has been divided into 4322 nodes, each node having an expected demand of priority one, two and three incidents. Depending on the average speed per BT, a coverage matrix is used to decide whether a vehicle is able to cover the distance between two nodes in-time. Each vehicle is expected to be busy 23% of the time. A vehicle allocated to a node, is able to service 77% of the incidents in-time, that it can reach in-time, from that node. Multiple vehicles covering the same node lead to a higher percentage of incidents covered on that node. The emergency distribution result has been verified using simulation. Within the simulation a more realistic process flow is used, incorporating vehicle assignment decisions to priority incidents and allowing for incidents being interrupted or having to wait. Equal demand per hour and the more realistic demand variation per hour show the same results as the distribution: 0 are not serviced in-time and 0 incidents are interrupted. This is better than a random allocation, 48% not serviced in-time and 6% interrupted, and when allocating vehicles at office locations, 20% not serviced in-time and 9% interrupted.

Civilian vehicles
For civilian vehicles, a queuing model is used to distribute vehicles (311 vehicles) across teams and locations[2]. Four scenarios are considered: 1) team vehicles and dedicated standby-services vehicles, 2) team vehicles incorporating standby-services, 3) location pools and dedicated standby-services

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[1] MEXCLP: Maximum Expected Coverage Location Problem. (Daskin, 1983)
[2] Teams active at multiple locations are handled as separate teams, team A, location 1 is a team and team A location 2 is a team.

vehicles and 4) location pools incorporating standby-services. Distributions are based on the arrival rate, service rate and FTE, either per team or aggregated to a location. Each team or location is handled as an M/M/c/K-queue. Vehicles are iteratively assigned to queues that have the highest probability of having to wait. Civilian vehicle distribution result has been verified using simulation. Within the simulation a more realistic process flow and workday shift is used[3]. The workdays cause any existing queues to reset every weekday and leads to the following results in waiting probabilities: 1) 2.5%, 2) 1.8%, 3) 0.05% and 4) 0.03% and average waiting times of: 1) 298.2 seconds, 2) 164.5 seconds, 3) 0.7 seconds and 4) 0.5 seconds.

Advice

To maximise the mobility the Unit should distribute the emergency vehicles to the Base Teams as shown in Table 1 and for civilian vehicles, pool vehicles at office locations and supply standby-service demand from these pools.

Table 1: Vehicle allocations per Base Team: shows the number of vehicles assigned to each Base Team.

Base Team	# of Vehicles
Den Helder	19
Heerhugowaard	18
Alkmaar	16
Hoorn	15
Haarlem	9
Haarlemmermeer	12
Kennemerkust	8
IJmond	9
Zaanstad	9
Purmerend	10

Emergency vehicles are not the bottleneck for incidents, consider further research into factors affecting response-times and the use of vehicle distribution models as a tool for the DROC[4], considering the provided coverage. The available set of civilian vehicles should be able to handle all demand. Look for a fitting vehicle sharing system, that will provide access to all employees and that does not tie up vehicles in unnecessary reservations. Monitor the use of all vehicles in order to improve the fit of available vehicles to the needs of the Unit.

[3] For the validation, a simulation experiment without workday shifts has been used, showing a waiting probability of 8.9% compared to 9.0% of the distribution model.

[4] DROC: Dienst Regionaal Operationeel Centrum. The DROC receives all the calls of emergencies and has an overview of the entire Unit and its available emergency units.

1. Introduction

The subject of this research is fleet management for the police force of Noord-Holland. The research takes place during a national reorganisation. The 26 former districts are reformed into one National Unit, ten Regional Units and the supporting Police Services Centre (PDC - Politie Diensten Centrum). The national plans for the reorganisation will not only have its effects on the workforce, but also bring changes to the fleet of vehicles. The period between the ‘Ist’ and ‘Soll’ situation (Nationale Politie, december 2012) brings ambiguity to the organisation. Not in the least because some plans are worked out during the reorganisation.

On a national scale a new vehicle project, the Strategic Vehicle Plan (SVP), has been started. This project should result in new contracts with suppliers of vehicles and maintenance and provide guidelines in the number of vehicles and/or budgets available for vehicles for the Dutch police force. The SVP does leave some options open in the assignment of vehicles, such as the specific number of vehicles to be assigned to each location, and the number of vehicles to be assigned to each team.

The reorganization changes the structure of the departments and teams. Some teams are discontinued and incorporated in other teams, other teams are enlarged or made smaller and some teams are newly formed. Many teams need to operate in the larger Unit-region instead of the smaller, separate districts, thereby increasing the area they need to cover.

With the upcoming formation changes, people were moving to different positions and teams. However, there was a lack of a plan to move the vehicles. Though teams were reorganized, vehicles largely remained with the same teams or persons. Relocating vehicles appeared to be a difficult task because teams want to make sure they do not have a lack of vehicles. The management of the Unit of Noord-Holland (Unit) has the idea that there are enough vehicles present. To find out whether this is true they issued a research in which all the vehicles of the Unit should be identified and listed. The research resulted in a list containing about 850 vehicles. Compared to other regional units, Noord-Holland was well supplied. However, this did not solve the problem of teams which are in need of vehicles.

The national plan seems to create an increase in the mobility requirement and on the other hand the resources to facilitate mobility will be limited. The question then arises how the vehicles should be assigned to the teams in order to facilitate teams with the necessary vehicles, while staying within the given boundaries. The problem of the Unit is how it should redistribute its existing fleet. The distribution of vehicles should fit the mobility requirements of the teams and the Unit as a whole.

1.1 Research Focus

The Unit has to find a way to redistribute its vehicles such that the police can function properly and do the jobs they are assigned to do. The problem is that the Unit management does not know what the right distribution should be. They want to know where vehicles are needed and how the fleet should be managed.

Currently the distribution does not fit the new organization. The Unit management hears a lot of concerns about vehicles, causing employees to remain without vehicles impairing their mobility and their effectiveness in executing their duties. The core of the duties of the Dutch police force is formulated in the Politiewet (Opstelten, Politiewet 2012, 2012):

"De politie heeft tot taak in ondergeschiktheid aan het bevoegd gezag en in overeenstemming met de geldende rechtsregels te zorgen voor de daadwerkelijke handhaving van de rechtsorde en het verlenen van hulp aan hen die deze behoeven."

Translated this means that the duty of the police is, in compliance to the ruling office and the rules of law, to maintain and enforce law and order and to aid those who require assistance. The police have a legal obligation to perform the tasks that they are assigned to do. Distributing vehicles is an important part in being able to fulfil this obligation. The vehicles should provide for the mobility requirement arising from the tasks. The mobility requirement in this thesis is defined as the vehicles usage of the employees.

The new organizational Unit is comprised of three districts. Each of these districts has had a lot of autonomy in how to manage their processes. The merger of the districts also caused a merger of these processes causing ambiguity about which rules and policies to comply to. In addition, departments and teams were being reformed.

The goal of the reorganization is to encourage more cooperation and specialization in various fields. This should increase the performance of the police force in the changing society (Nationale Politie, december 2012). The Base Teams (BTs) remained largely the same, but more specialized teams were combined or divided to encourage more specialization. Another change has been the implementation of dedicated Flex teams designed to cope with changing areas of attention.

The reorganization caused people having to change their locations of employment. This caused an increase in the mobility requirement because some employees needed transportation to their new locations of employment. Another increase in the requirement is due to ambiguities and uncertainties in the organization of their tasks. The uncertainties and changes in teams resulted in an increase in meetings throughout the Unit and beyond in order to ensure the cooperation within the newly formed teams. Already existing teams are reluctant to relinquish vehicles assigned to them because of the (expected) increase in their mobility requirement. This reluctance in relinquishing vehicles to other teams is causing some of the teams to be without vehicles.

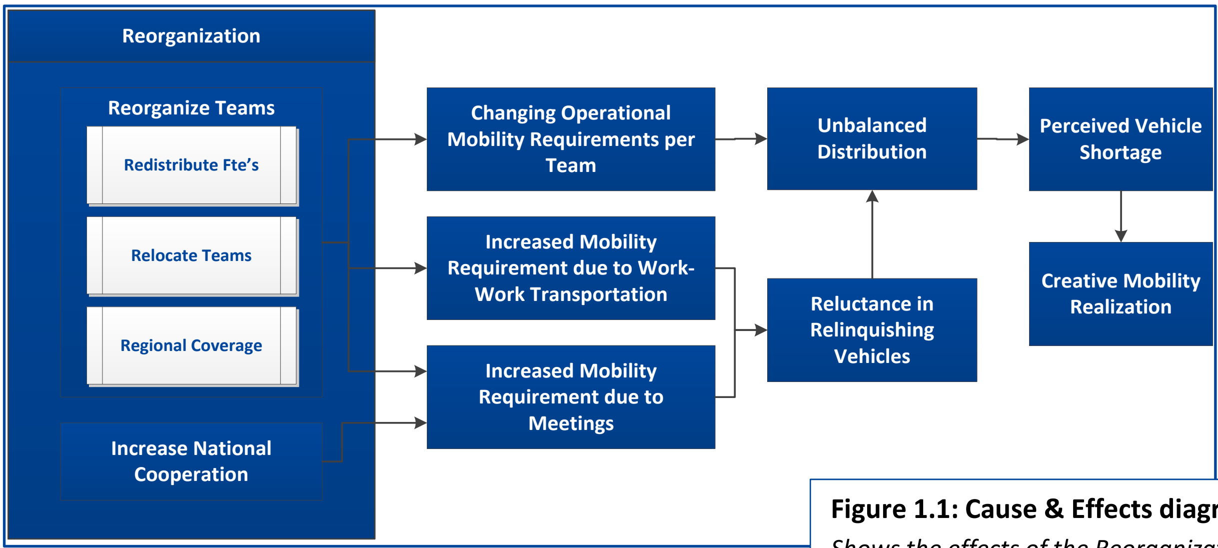

Figure 1.1: Cause & Effects diagram
Shows the effects of the Reorganization on the mobility requirement of the Unit.

The problem of perceiving[5] a shortage of vehicles results from the reorganization. The way this takes place is illustrated in Figure 1.1. The reason for a perceived vehicle shortage is due to the reorganization. The reorganization will continue as ordered by the Dutch government. This means that the changes in the operational mobility requirements will also take place. The first next step is to redistribute the vehicles in order to get a more balanced distribution of vehicles which will reduce the perceived vehicle shortage. Another reason is that some teams really are short on vehicles, however it is unclear whether there is a Unit wide shortage, or whether it is only due to an unbalance in the distribution. An effect of the perceived shortage is an increase in employees finding their own way of realizing their mobility. This may result in high reimbursements of travel expenses or unofficial use of vehicles. The creative realization due to a lack of vehicles should be incidental and not become standard.

Employees say they are short on vehicles. As a researcher I would like to see this in some of the data. One of the reasons may be an unbalanced distribution which is in part caused by the reluctance of relinquishing vehicles. This is due to the fact that the mobility requirement of several teams has increased as a result of more meetings (regionally and nationally) and as a result of the repositioning of employees, changing their work locations. Part of the solution will consist of reducing the mobility requirement and to redistributing the vehicles.

1.2 Police Goals

How the problem may be solved depends on the goals and results the Unit management wants to achieve. The way in which vehicles are to be redistributed should result from the goals the police force sets on both the national and regional level.

On a national level disrupting criminal collaborations is a focal point as is the reducing cybercrimes in this age of growing computer usage. Forms of human trafficking and child abuse/pornography remain important areas of focus due to the nature and impact of these crimes. The response of the emergency service in the case of incidents is an important, visible parameter which should be maximized. The response time however, is not legally bound (Berg, WOB verzoek - RTL Nieuws, 2012). A rule which is legally bound is the number of district-officers (wijkagent), one for each 5000 inhabitants (Opstelten, Politiewet 2012, 2012). The organization plan (Nationale Politie, december 2012) aims to fulfil these goals and more. The design of the police force is based on the mission and core values:

> *“Onveranderbaar is de politie ‘waakzaam en dienstbaar’ aan de waarden van de rechtstaat.”*

‘Unchangeably the police force is vigilant and serviceable to the values of the constitutional state.’ The goals are to make the Netherlands a safe place, and to provide room for police employees to execute their professionalism.

With regard to the fleet, a strategic vehicle plan (SVP) is being made for the entirety of the Dutch police force. This plan involves the procurement of vehicles and a distribution over the Units. The SVP will determine the boundaries within which the distribution of vehicles should take place. The question for the Units then remains how the vehicles should be distributed within the Unit. The SVP

[5] Perceived: In this case perceived shortage is because there is no definitive prove of a real shortage.

decides the vehicle capacity on a strategic level. What the exact bounds will be is still uncertain. The expectation is that the bounds will involve budgetary and/or vehicle quota.

On a regional level the goals are divided over several areas of attention. The general number of crimes should be reduced and suspect ratios are to be maximized (increased efficiency). Furthermore, special attention is given to High Impact Crimes[6] (HICs), mugging, robberies, burglaries, violence and confiscations. Confiscations are an important part of discouraging organized crimes as illegally claimed properties are being claimed (Crime does not pay). Preventive measures are found in the approach concerning youths. All these goals are an important part of the local crime fighting approach and crime prevention. Keeping in touch with society. Tables 1.1 and 1.2 show the assembled KPI's as mentioned in the Annual report of the Unit (Eenheid Noord-Holland, 2013).

Regional Priorities	Goal	Result
Crimes		
Suspect ratio	20%	19%
# of Crimes	≤89.589	87.506
High Impact Crimes		
Suspect ratio	36%	40%
# of High Impact Crimes	≤15.662	15.226
Report Informer	100%	99,5%
Mugging		
Suspect ratio	35%	41%
# of Muggings	361	351
Robbery		
Suspect ratio	44%	92%
# of Robberies	152	130
Clearing rate	36%	55%
Burglaries		
Suspect ratio	7%	8%
# of Burglaries	593	588
Clearing rate	14%	9%
Violence		
Suspect ratio	58%	68%
# of Violent acts	≤5.200	5.244
# Against Police	≤442	336
# Against Civil Servents	≤147	132
Honor Related Violence		
Statements	-	389
Sent to LEC*	-	51
Transferred to Prosecutor	-	27
Youth		
File to Prosecuter <30 Days	80%	74%
Referred to HALT < 7 Days	80%	80%
Antisocial groups		6
Troublesome groups		28
Criminal groups		6
Confiscation		
Confiscation ratio	45%	34%
Total Value	€ 7.733.094,00	€ 8.509.901,00
# of Files		137

National Priorities	Goal	Result
Service Provision		
Response Time Prio-1	80%	89%
Repsonse Time Prio-2	80%	86%
Reply LTP	80%	72%
Weapon License Check		
Executed Checks	100%	88%
CSV**		
# Treated	14	57
Start pre-2013		23
Start in-2013		24
Cybercrime		
Registered Cases		139
# CSV's Fraud/Cybercrime**		7
Human Trafficing		
CSV Investigations (level 1, 2, 3)**		14
Child Pronography		
Rise of Suspects	25%	15%
# of Suspects		546
File to Prosecuter		29
Verbal Statement (non-Dutch)		
Non-Dutch Suspects	2055	1857
Files with V-number	100%	73%
Quality ID Investigatio	87%	93%
Discrimination		
# Registered		452

The two tables show the priorities and goals set by the Unit for 2013 and the results of 2013.

*LEC: Landelijk Eergerelateerd Geweldscentrum (National Honor-Related Violence Centre)
**CSV: Criminele Samenwerkingsverbanden (Criminal Collaborations)

Table 1.1 (left) and 1.2 (right): Goals & Results
These tables show the goals and results from 2013. Table 1.1 shows them on a Regional level and Table 1.2 on a National level.

In addition to the goals defined in the annual report, the management of the Unit has defined some goals for the research. The management would like to gain insight into the (vehicular) mobility

[6] HICs: Crimes with a high personal impact, such as muggings, robberies, burglaries and acts of violence (Opstelten, Aanpak High Impact Crimes, 2013).

requirement of the Unit. They want to know what ideas are thought of within the Unit and clarify how the vehicles should be used. They want to maximize the on-time responses on incidents and know how the vehicles may be distributed to equalize the vehicular facilitation.

Furthermore, the Unit management would like to gain insight in the options and effects of a formal shared vehicle system. The sharing of vehicles already takes place formally with a small pool of vehicles at three locations and informally between teams by calling an acquaintance in another team. The idea is that the sharing of vehicles may be scaled-up to envelop the entire Unit and improve vehicle sharing amongst all teams. By sharing vehicles, the efficiency may be increased and the chances of missing out on a vehicle may be reduced. A distribution method should be reusable in order to cope with adjustments in the mobility requirements.

With regard to the quantified KPIs, we need to be aware that determining the performance of the police force is a complicated task (Zouridis, Idema, Koppe, Reniers, & Theuns, 2011). The police exist to keep law and order, essentially to stop criminals from being criminal and to make sure everyone follows the law. This is also reflected in their annual reports (Eenheid Noord-Holland, 2013) & (Nationale Politie, 2014). The performance of the police should only be measured in numerical indicators to a certain extent. Focussing too much on numbers of performance measures may result in perverted acts (Morée, Hoorweg, & Koppes, 2007). Perverted acts are not in line with police goals. People should feel safe and treated fairly, results achieved on an emotional level. The back and forth motion between numerically achieved results and emotionally achieved results is also reflected in the Design plan of the National Police (Nationale Politie, december 2012).

To summarise, the goals and KPIs defined by the police force indicate that they try to minimize criminality by defining a maximum number of crimes[7], they want to increase the efficiency by setting minimal percentages of suspect ratios (identified suspects per crime) and they want to maximize the number of on-time response times (getting to an incident within 15 minutes).

1.3 Research scope

The research objective is to optimize the mobility of the Unit by distributing the vehicles. Limitations to the project are defined in the SVP. The SVP defines the distribution of vehicles on the Unit-level and partly on the team-level. Defined in this plan are the total number of vehicles available to the Unit, the number of specialized vehicles and a minimal number of vehicles for each BT. Covert vehicles are out of scope.

Besides the limitations imposed by the police organization, some practical limitations should be taken into account. It is impractical to define a solution which requires a large number of new vehicles. An overhaul of the current fleet is out of the question.

The scope of the research encompasses the distribution of the striped and civilian vehicles. With regard to the civilian vehicles, the effects of pooling/grouping these vehicles have to be investigated. In combination with the goal of priority-one incidents for striped vehicles, this will result in a separate distribution for striped and civilian vehicles.

[7] Minimizing the number of crimes: The police is obliged to consider all crime statements given (Opstelten, Politiewet 2012, 2012).

1.4 Research Approach

With the focus and goals identified, the research questions must be defined. The principal research question is:

> *How should the Unit of Noord-Holland redistribute its vehicles across Noord-Holland, to maximize its mobility?*

In order to gain insight to the current situation and the use of the vehicles, information has to be gathered and analysed. The basis for the distribution of vehicles will be the vehicle usage. The vehicle usage can be defined based on a qualitative and quantitative aspects. The qualitative aspects give insight into what the vehicles are used for. The quantitative aspect will give insights into the actual use of vehicles. To know whether the distribution will satisfy the goals of the police force, the goals need to be linked to the distribution/availability of the vehicles. This will be done in Chapter 2. The chapter will focus on research questions one, two and three.

1. What are the vehicles used for?
2. What is the actual use of the vehicles?
3. How should the goals of the Police Force link to the distribution of vehicles?

When the current situation has been explored, the options for improving the situation can be explored. This is done using a literature study in which existing solutions for similar problems are considered. The literature study will be done in Chapter 3, focussing on questions four and five.

4. Which methods can be used to distribute emergency vehicles?
5. What can be the effects of vehicle sharing for the vehicle usage?

After considering several options, one or more distribution models will be presented with which the Unit may maximize their mobility. I addition the different models and/or configurations of the model(s) will be discussed to define the considerations to be made. Chapter 4 will focus on the models and the considerations that come with these models.

6. Which models are used to distribute the vehicles of the Unit?
7. Which model configuration fits the main question best?

Knowing what the model will look like, and which considerations should be considered, the performance of the models can be analysed or simulated. For this research the models will be simulated. A simulation model will be made in order to perform experiments with the distributions made. The experiments and their results will provide further insights on the distributions and expected reactions. Based on the gained insights and results, a final proposal can be defined with which the Unit can improve the mobility of their employees. Chapter 5 will focus on the simulation model. Question eight, nine and ten will be answered in this chapter.

8. With which model/within which boundaries will the simulation study take place?
9. What is the expected performance of the tested scenarios?

The final chapter, Chapter 6, will answer the main research question. *How should the Unit of Noord-Holland redistribute its vehicles across Noord-Holland, to maximize its mobility?*

2. Data Analysis

This chapter focusses on the data analysis. The goal of the data analysis is to gain insights to the required mobility of the Unit and how current performance measures can be related to the distribution of vehicles. The following data is available:

1) A list of reported incidents and response times (2010 and 2011)
2) Aggregated data for priority 1, 2 and 3 (2015)
3) A list of key releases
4) A list of vehicles
5) A data summary for each Base Team (BT)

Further information has been gathered from the Unit by interviews with the leaders of departments and teams. This information provides an indication of the work each team does and what the vehicles are used for.

This chapter answers the following research questions:

1. What are the vehicles used for?
2. What is the actual use of the vehicles?
3. How should the goals of the Police Force link to the distribution of vehicles?

2.1 Interviews

The interviews provide data on which vehicles are used by the teams and an idea on how they are used. The questions of the interview can be found in Appendix A. This paragraph gives a summary of the information gathered with the interviews.

2.1.1 Users

The Unit employs about 4500 people, divided among 3458 FTE's. These people are divided into different departments and teams. Each team focusses on their assigned jobs. To give an overview of the teams, a chart of the organization structure has been made as shown in Figure 2.1.

The Unit is divided in functional teams. These teams work from several locations and sometimes teams switch from work locations. This may be due to an investigation, which has to be performed from another location. However, generally employees are stationed at one location. The vehicle distribution should take these starting positions in consideration instead of locations form which work is initiated.

2.1.2 Working processes

Vehicles are used for a wide range of processes. 24/7 vehicles have to be ready for emergencies, investigative cases, surveillance, projects, meetings and standby-services. There is a large variety of tasks for the different services of the police, requiring many different forms of specialization.

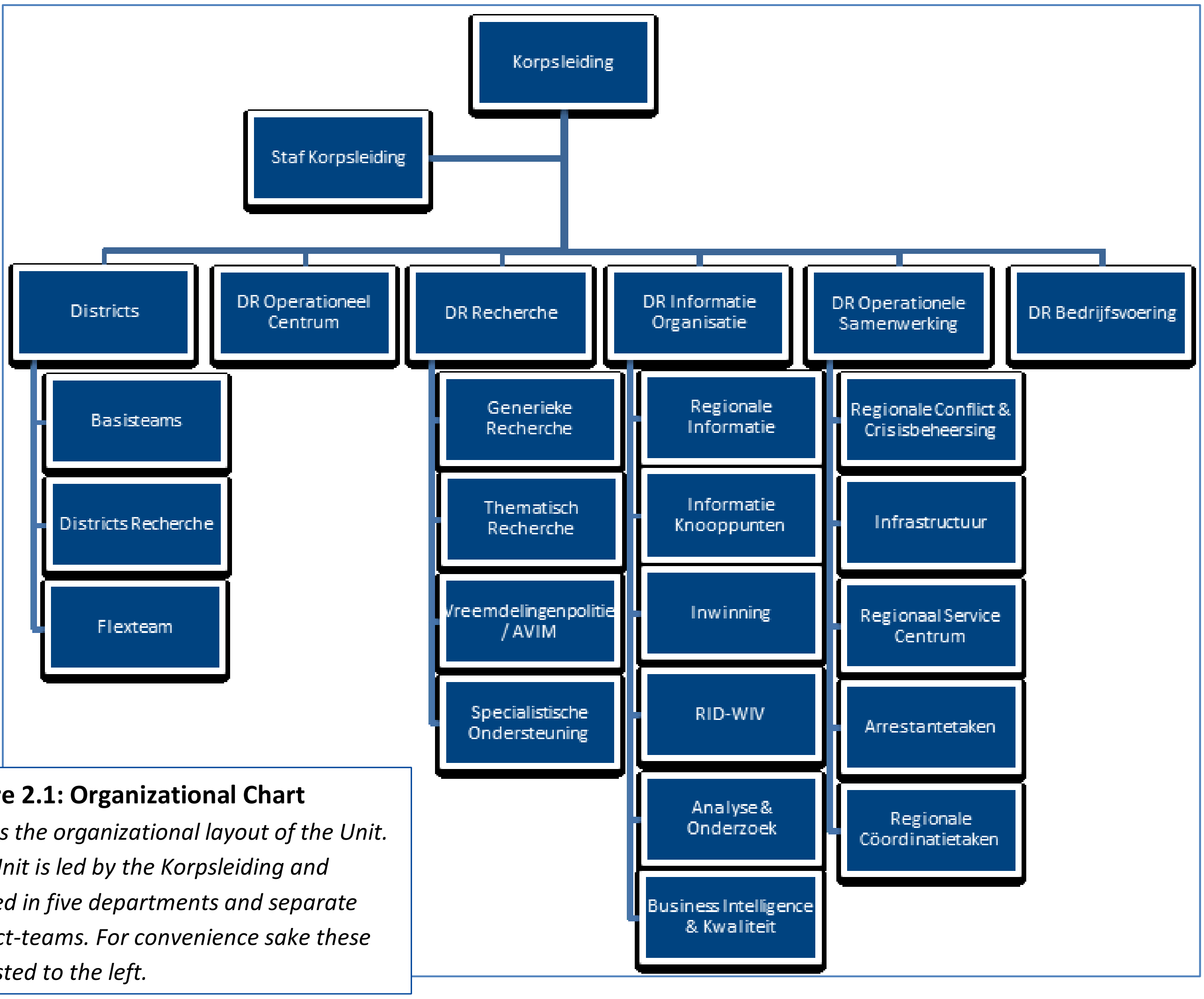

Figure 2.1: Organizational Chart
Shows the organizational layout of the Unit. The Unit is led by the Korpsleiding and divided in five departments and separate district-teams. For convenience sake these are listed to the left.

2.1.2.1 Law on police

An important part of the working processes is based on the Dutch Law on police, the Politiewet (Opstelten, Politiewet 2012, 2012):

> *"De politie heeft tot taak in ondergeschiktheid aan het bevoegd gezag en in overeenstemming met de geldende rechtsregels te zorgen voor de daadwerkelijke handhaving van de rechtsorde en het verlenen van hulp aan hen die deze behoeven."*

In translation this means that the duty of the police is, in compliance to the ruling office and the rules of law, to maintain and enforce law and order and to aid those who require assistance. Investigations of the police have to be done within the legal framework. An investigation is described in a police report. Usually such a report starts with a statement or an observation. Based on the contents of the report subsequent steps have to be made. Subsequent steps may consist of hearing witnesses or suspects and conducting house searches and forensics. The report gives rise to an investigation and this in turn may lead to a requirement in the mobility. The mobility required varies for each report.

2.1.2.2 Emergencies

One of the basic tasks of the police force is to provide aid to those in need. One of the key elements in executing these tasks is to provide aid in case of an emergency. Emergencies are reported to the emergency control room (Meldkamer). The control room directs police officers in the field and primarily houses the department Dienst Regionaal Operationeel Centrum (DROC), team Regionaal Service Centrum (RSC) and team Real-Time Intelligence Centre (RTIC[8]). Together they receive reports and process them to inform and direct officers and other employees. The keep an overview of all active police units (individuals or teams). There is a detailed map available showing the locations of reported incidents and units. The control room is able to provide directions and manage the coverage of incidents. Emergencies may require one or multiple vehicles depending on the incident. This is especially true in regions where solo-surveillance is being done in order to achieve the desired coverage of on-time responses. An on-time response is defined as the time between the reported incident coming in at the control room and the officers arriving at the location of the incident. Incidents are divided into three priority types. The first priority type consists of emergencies that require immediate attention of officers. From the 112-call to the arrival of the officers should take 15 minutes max. For example, a traffic accident with life threatening injuries and/or danger to the public. Priority two incidents also require officers to get there in-time, however the need to be there as fast as possible is less than a priority one. For example, a traffic incident where a vehicle is total loss without people being badly hurt. Priority three incidents will also require assistance of officers, however there is no immediate danger to the public. For example, a disagreement between neighbours on the use of a balcony. There is no response-time defined for priority three incidents.

2.1.2.3 Investigations

In order to maintain law and order, the police have to know who the people are who break the law and what they did. To this end investigations take place. The investigations are used to track down criminals and to gather evidence in order to be sure the criminal is a real criminal and can be brought to justice and evicted. Investigations may require that employees should visit a certain location, getting statements, retrieving information and/or evidence. Some investigations require the use of specialized equipment.

2.1.2.4 Standby-services

Standby-services are used in addition to the emergency force. Employees are on standby-service in order to assist when an incident requires additional expertise. Employees on standby-service are available if the current capacity or expertise is not enough. Standby-services are performed in addition to the emergency services and are available 24/7. The Unit has about 38 different types of standby-services, most of them requiring multiple employees[9]. Standby-services are used to provide adequate support in case of an emergency or urgent event. They are employed during and outside office hours. When an employee is on standby-service he/she is expected to be able to respond to emergencies within a short time frame[10].

Some standby-service requires the use of specialized vehicles, other standby-services only require simple transportation and can be supplied by civilian vehicles. The frequency with which the standby-services are required may vary greatly between the different kinds of standby-services. Some services are required several times a week and others may only be required once a year. Most services have a response time of 30 minutes. The services using specialized vehicles generally have

[8] Part of the team of Regionale Informatie from the department of DR Informatie Organisatie.

[9] A complete description of the standby-services and the recommended guidelines can be found in a separate document, available internally for the police.

[10] Time frames for standby-services may vary between different types. Most time frames are 30 minutes long, form call to being at the location where they are required.

no problem with mobility because they are used only by a select group of users. The standby-services using civilian vehicles are different though. This type of vehicle is in use with each team. The vehicles are used for standby-services and also for other activities such as meetings and investigations. Reserving capacity for standby-services may conflict with these other activities. It may very well be that a reserved vehicle may remain idle for several days. During this time other employees may have been short on vehicles, impairing their mobility.

2.1.2.5 Supporting tasks

In addition to the mobility requirement of the operational side, there is a mobility requirement for the supporting tasks. The requirement for supporting of tasks is generally transportation between police stations, requiring transportation of personnel between offices for meetings. These tasks enable the police force to effectively execute the tasks assigned to them by the law of police (Opstelten, Politiewet 2012, 2012).

2.2 Base Team summary

There are ten BTs in the unit. A summary showing a few key factors of the BT's is shown in Table 2.1. The geographic locations are visualized in Figure 2.2.

District	Base Team	Incidents	Population	Area size (km^2)	FTEs
KEN	Haarlem	35.631	153.093	29,22	215
KEN	Haarlemmermeer	28.471	149.679	197,9	165
KEN	IJmond	32.282	159.37	109,57	185
KEN	Kennemerkust	13.137	65.105	81,03	110
NHN	Alkmaar	38.608	193.764	282,84	200
NHN	Den Helder	24.002	119.816	374,28	165
NHN	Heerhugowaard	20.578	149.811	501,05	150
NHN	Hoorn	31.972	185.03	269,78	190
ZAW	Zaanstad	33.229	174.503	124,15	200
ZAW	Purmerend	20.72	150.883	223,01	155
	Totals:	**257.91**	**1.350.171**	**1970**	**1735**

Table 2.1: Base Team Summary: Shows the size of each region by the number of FTE's, the region size in squared km's, the population and the number of incidents.

The number of FTE's and the number of incidents per team have a high correlation ($correlation\ coefficient$: 0.96). The distribution of employee capacity is clearly linked to the number of incidents. It seems logical to distribute the vehicles for the BTs according to the number of incidents, because vehicles are required to service the incidents. However, there are more factors that should be considered.

The population also shows a high correlation compared to the number of incidents ($correlation\ coefficient$: 0.83). This seems only natural due to the fact that with more people we may expect more incidents. There appears to be some correlation between the number of inhabitants per incident and the size of the region ($correlation\ coefficient$: 0.62). This indicates that the number of incidents is relatively lower in rural areas compared to urban areas. Thus, requiring relatively less employees and vehicles for rural areas. The distance that has to be travelled for rural areas is generally higher though.

The area size of the regions plays an important role. Small regions may be directly serviced from an office location, while large rural areas may require service by placing officers on surveillance on strategic locations. The deployment of the surveillance teams provides the coverage required to deal with the reported incidents in-time. The increase in performance by placement of vehicles in certain areas has been proven by Muller (2014). One of the surveillance methods seen in rural areas is the so-called Solo surveillance. With Solo surveillance, each vehicle is driven by one officer instead of the regular two officers and the vehicles are spread across the region. This increases the flexibility in mobility. Having more mobile units in an area to respond to incidents reduces the need for multiple police stations as these incidents can be serviced by the mobile units instead of a fixed base location. Solo surveillance is used most extensively in the district NHN to make sure response times stay within bounds. The relative size of the areas is shown in column ´Area size´ of Table 3. Table 3 shows that the largest regions can be found in the northern part of the Unit. District NHN accounts for 65% of the Unit's total area. Based on the interviews, it is generally acknowledged that rural areas should be provided with additional vehicles compared to urban areas, as the general idea is that rural areas have too few vehicles to cover all the demand.

The teams that are mostly affected by the differences in region size are the BTs. The BTs are assigned to specific regions. This also holds for the district investigative services (Districts Recherche – DR) and Flex teams who are assigned to specific districts (NHN, ZAW or KEN). Other teams have to span the entire area of the Unit and thus the differences between region sizes play less of a role.

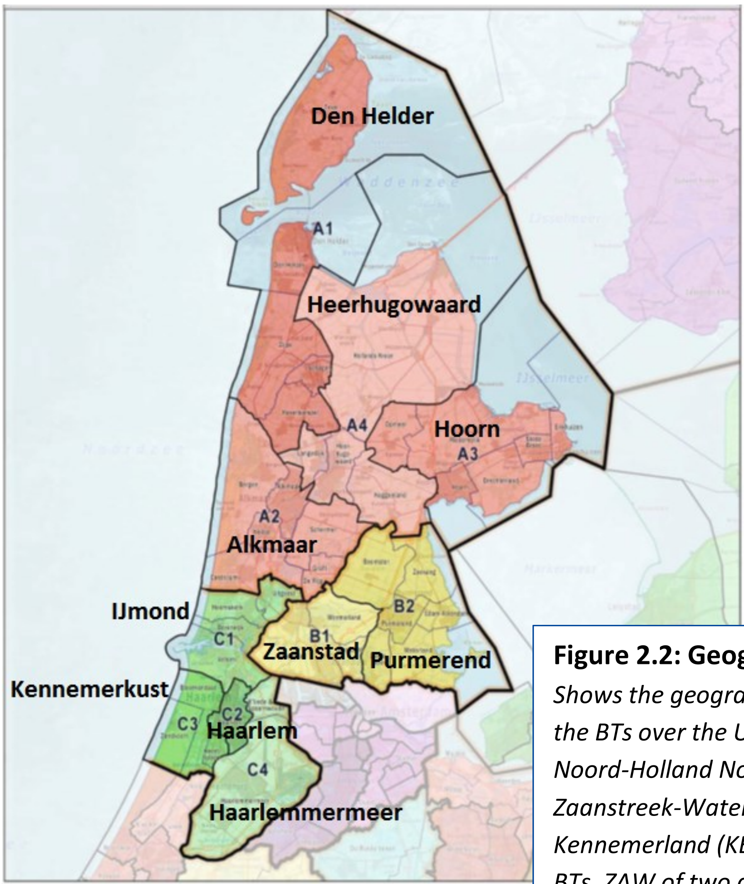

Figure 2.2: Geography of the Unit
Shows the geographical distribution of the BTs over the Unit. The red region is Noord-Holland Noord (NHN), yellow is Zaanstreek-Waterland (ZAW) and green is Kennemerland (KEN). KEN consists of four BTs, ZAW of two and NHN of four.

2.3 Current Fleet

An assessment of the fleet has been made prior to this research. The goal of the assessment was to identify and locate all vehicles in order to get a look at the true formation of the fleet. The fleet consists of about 843 vehicles. The vehicles of the fleet have been coded, resulting in 78 differently coded vehicles (85 codes are defined on a national scale). The 78 codes show a wide array of vehicles. Having all these separate codes seems to be cumbersome and causes unnecessary complexities. The differences between some of the codes is limited. An example is a civilian vehicle containing an investigative case and a regular civilian vehicle. The case can be taken out of a vehicle and placed in another vehicle, which would cause the vehicles to switch codes.

Looking at the data, differences in defining the vehicle codes can be found. An example is the OVDP[11] vehicle. For some teams these vehicles were defined as OVDP, other teams defined these vehicles as emergency vehicles, with a side note that they were used as OVDP vehicles. Both definitions are not wrong, since the OVDP vehicle is equipped to deal with emergencies. However, it does pose a form of noise in the data. To make the data clearer, the vehicles have been redefined into four categories. The categories are listed below, a more elaborate description is added after the list.

1. **Civilian vehicles**: These vehicles may be used by all employees. They can be used to move employees from one place to the next like meetings and appointments. These vehicles are not recognizable as police cars.
2. **Striped vehicles**: These are vehicles directly recognizable as being police vehicles. They are used for a wide array of tasks and are mostly used by BTs. A subdivision can be made to the following subcategories:
    a. **Emergency:** Basic vehicle, fully equipped for emergencies.
    b. **Surveillance:** Striped, but not fully equipped for emergencies.
    c. **Heavy motorcycle:** Motorcycle equipped for emergencies and highway surveillance.
    d. **Light motorcycle:** Motorcycle ideal for urban surveillance.
    e. **Transport bus**: Used for transportation of goods (e.g. moped).
    f. **Passenger bus:** Used to transport a small group of employees.
    g. **OVDP/OpCo[7]:** Creates a work location on the spot, used for larger incidents.
3. **Specialized vehicles**: This group of vehicles are specially adapted to suit specific needs. Specialized vehicles are used by a single team, for a specific purpose.
4. **Covert vehicles**: These vehicles are unrecognizable as police vehicles. Their goal is to remain hidden from criminal eyes.

2.3.1 Civilian vehicles

Civilian vehicles can be used for general movements. Movements for which these vehicles are used are: meetings, standby-services, and investigations for which recognition is unnecessary or discretion is wanted. Discrete vehicles are used throughout the organization and offer a viable option for vehicle sharing. Options and consequences of a shared vehicle system are discussed in Section 3.2. To improve the usability of civilian vehicles, several employees proposed to provide vehicles with mobile resources, which can be transferred easily between vehicles.

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[11] OVDP/OpCo: OVDP is the Officer of Service Police (Officier van Dienst Politie), in absence his duties are taken over by an OpCo, Operational Coordinator. The OVDP vehicle is generally used in case an incident scaled-up, requiring additional coordination.

2.3.2 Striped vehicles
Striped vehicles are primarily used for emergency calls and surveillances. Employee groups who use them are generally part of a base team, officers designated to offer emergency assistance or neighbourhood control. When an emergency occurs, officers in striped vehicles are obliged to respond due to the law of police (Opstelten, Politiewet 2012, 2012). Because of the size of the BT's and the variable demand in transportation/task requirements, different types of vehicles are involved. The main vehicle for BTs is the emergency vehicle. This is also shown in the number of vehicles of this type (125 for the Unit). The other striped vehicles for the BT's are more specialized vehicles for specific needs of these teams.

The distribution of striped vehicles in this study will only include one type of striped vehicles: emergency vehicles. This is because other types of vehicles are only present in small numbers (from zero to three vehicles per BT). The distribution of the more specialized striped vehicles also depends on characteristics such as length and number of highways, presence of beaches, off-road terrain, recreational waterways and more. Surveillance vehicles will be included in the count to emergency vehicles, because these vehicles are supposed to execute the same tasks as emergency vehicles in the near future.

2.3.3 Specialized vehicles
Same tasks require the use of specialized vehicles. An example of specialized vehicles are the ME busses used to control up scaled crisis and conflicts. Specialized vehicles are limited in their usability and are generally used by a select group of employees. In most cases, specialized vehicles are only used by a single team. Furthermore, the number of specialized vehicles is likely to be determined by the national SVP. The employment of specialized vehicles is highly related to types of tasks and options for distributing specialized vehicles will most-likely be absent due to the plans already determined in the SVP. In addition, the individual teams probably have a much better understanding of where to deploy these vehicles best. Because the number of specialized vehicles may not be changed and because specialists will have a better understanding of how to place these vehicles, it is unnecessary at this point to try to distribute specialized vehicles.

2.3.4 Covert vehicles
Beside the 'known' and recognizable vehicles, there is a group of covert vehicles. These are vehicles that are not to be linked to the police force. Because of this and due to the fact that these vehicles are mostly used by only one or two persons per vehicle, these vehicles will be kept out of the distribution models considered further on in this research.

2.4 Key Releases
At three locations a vehicle pool is available. These locations are Haarlem Koudenhorn, Zaandijk De Guishof and Alkmaar James Wattstraat. At Haarlem a digital key cabinet is present. This Section will look into the data of this digital key cabinet. The digital Key cabinet shows the release and retrieval of keys of civilian vehicles. As said, the civilian vehicles are used for general mobility requirements such as meetings. Through the years this has already resulted in a small system of shared vehicles. Up until recently these vehicles were formally only available to the internal services centre.

The digital key cabinet shows the date and time during which a key has been released to a person. The data shows a wide variety of key releases with a minimal release time of 26 seconds to a maximum of ten days. To implement a shared vehicle system, the management of the Unit has indicated that for single rides the duration should not be longer than a day. The basis of this idea, is that generally the employees use the vehicle during their shift. Since most shifts will not exceed eight hours, the rule of thumb is that vehicles should not be used longer than a day. Because of the possibility on night shifts and extended working days (for example due to a national meeting at the other side of the Netherlands) the maximum duration of a key release should be 24 hours.

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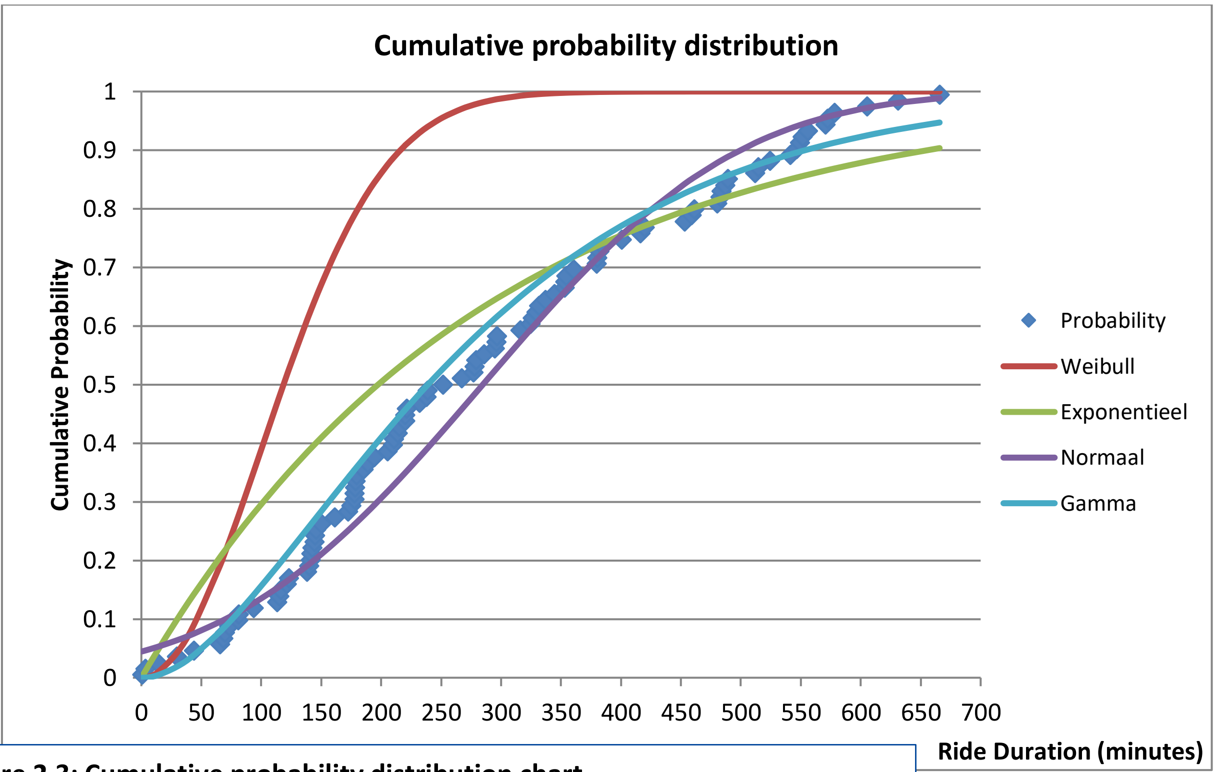


Figure 2.3: Cumulative probability distribution chart
This chart shows the cumulative probability of the ride durations as determined by the data of the digital key cabinet. This is shown in the dotted line. The lines show the cumulative distribution of several probability distributions. The chart shows the resemblance of the probability distributions in relation to the real data in the dotted line.

The key releases of October 2015 show 97 data points of keys that were returned within 24 hours. To determine the probability distribution, the data has been compared to several probability distribution functions: The Normal, Exponential, Weibull and Gamma distribution. The data seems to get the best fit with the Gamma and Normal distribution. To determine the most likely distribution a Goodness of Fit (Chi-Square) test has been used (Larson & Marx, 2012, pp. 509-510). To determine the interval for the test, the following rules apply: More intervals, k, means a higher power of validity, $np_j \geq 5 \; \forall \; j$ and each interval should be of equal probability, $p_1 = p_2 = \cdots = p_k$. The size is set to $p_j = 0.1$, resulting in $k = 10$. The resulting intervals and the expected and observed amounts are shown in Tables 2.2 and 2.3.

Gamma			
Interval	Lower bound	Expected	Observed
1	0.00	9.7	9
2	75.72	9.7	6
3	117.38	9.7	11
4	156.25	9.7	11
5	195.99	9.7	11
6	238.98	9.7	6
7	287.96	9.7	10
8	347.32	9.7	11
9	426.36	9.7	15
10	553.86	9.7	7
	Sum	97	97

Normal			
Interval	Lower bound	Expected	Observed
1	0.00	9.7	8
2	70.06	9.7	14
3	143.77	9.7	15
4	196.92	9.7	11
5	242.33	9.7	5
6	284.78	9.7	7
7	327.23	9.7	8
8	372.64	9.7	7
9	425.79	9.7	8
10	499.50	9.7	14
	Sum	97	97

Table 2.2 and 2.3: Show the bounds of the intervals, the expected number of times within each interval and the observed number of times for each interval for the Gamma distribution (2.2) and the Normal distribution (2.3).

The acceptance value for both distributions is the same because both require the same *degrees of freedom* $(df = 7)$. The acceptance value X_7^2 = 14.07. The value of the test statistic for the Gamma distribution, $D_{Gamma} = 7.23$. The value of the test statistic for the Normal distribution, $D_{Normal} = 11.56$. Both values indicate that there is not enough evidence to reject the distributions. The test value is lower for the Gamma distribution, indicating that this distribution fits the data better, represents the data more closely. For that reason, it is assumed that the duration of key releases has a Gamma distribution with parameters $\alpha = 2, \; \beta = \frac{Average\ Duration}{\alpha} = 285\ minutes = \ 4.75\ hours$. The key releases are linked to persons. The next step could be to link the persons to teams in order to determine the mobility requirement of the teams using these cars. This process however, seems to be arduous because of the changes in personnel, switching teams and ambiguity about when people started working at their new positions.

2.5 Reported Incidents 2010-2011

The list of reported incidents consists of aggregated data of reported incidents for the three districts, Kennemerland (KEN), Noord-Holland Noord (NHN) and Zaanstreek-Waterland (ZAW). The data shows a list of reported incidents with a date, period of day (hour) and response time for each incident. There is no exact definition of which incidents are priority one, priority two or priority three. Each district is allowed to provide its own definition of priorities (Berg, WOB Verzoek - Aanrijtijden, 2012). The data is show per month, per week and in hour per weekday.

2.5.1 Incidents per Month

The incidents per month for each BT provides insight in the distribution of incidents over the course of a year as shown in Figure 2.4 and 2.5.

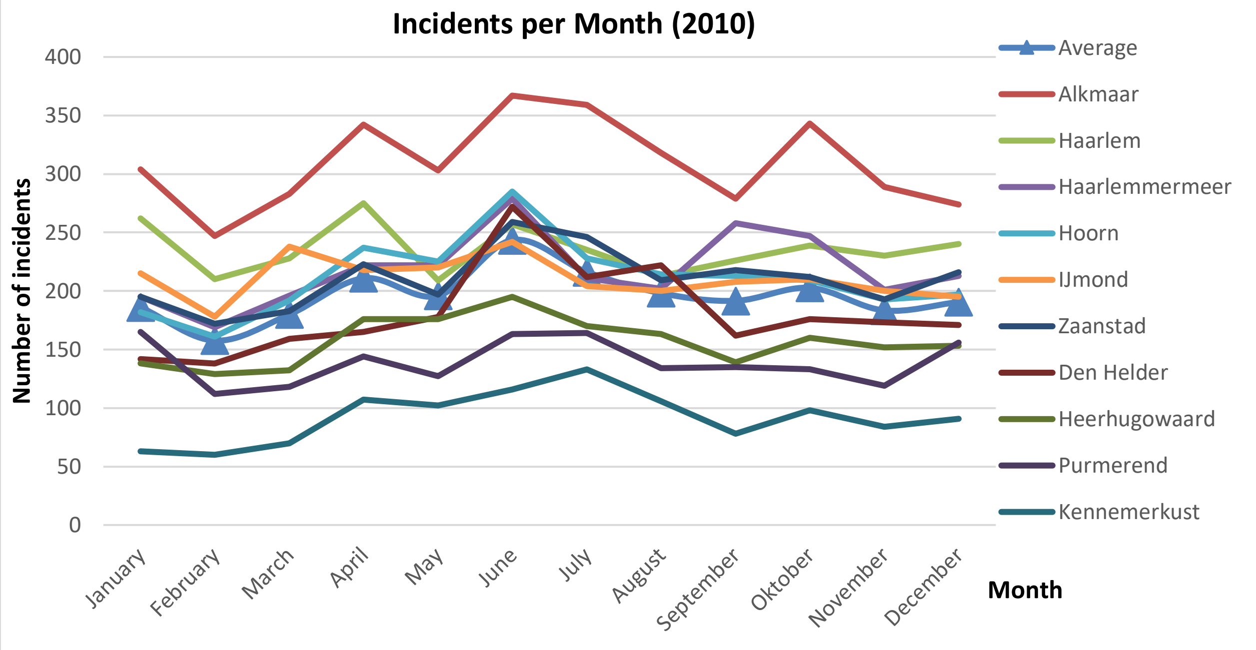
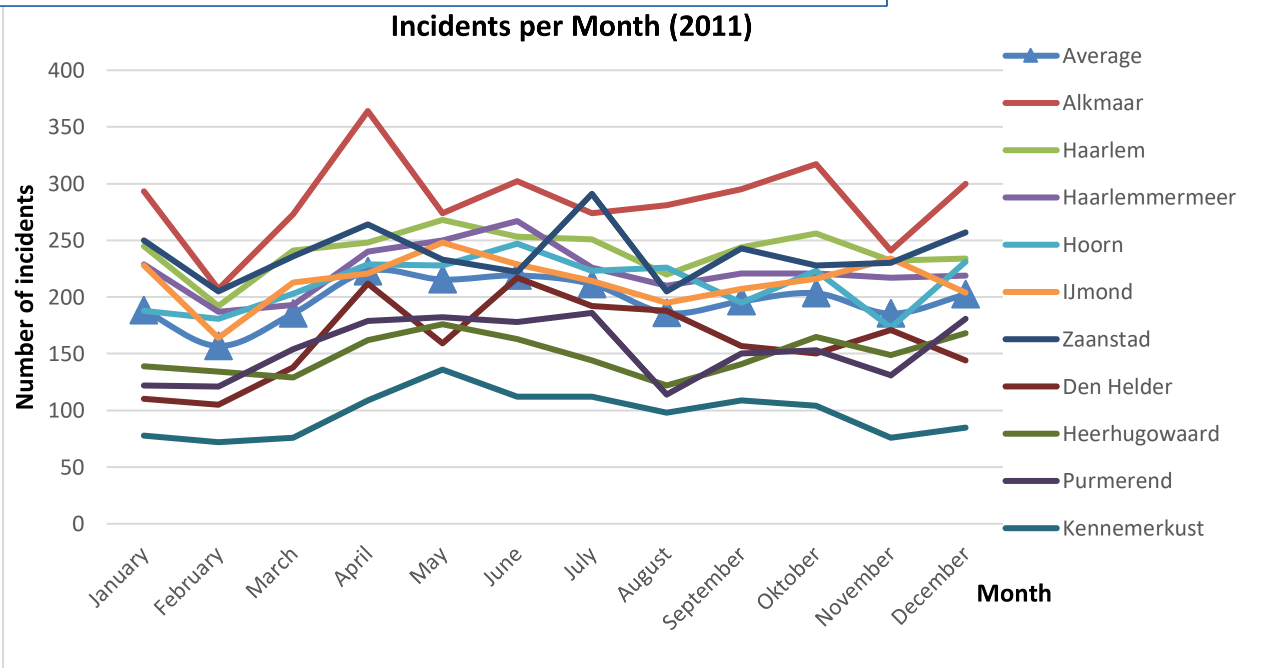


Figure 2.4 (up) and 2.5 (below): Incidents per Month for each BT
Charts 2.4 and 2.5 show the number of incidents that occur each month. The counts of incidents seem to vary each month. There seems to be an increase in incidents starting from April backing down again in July. The BTs are ranked by incident load, from high to low, in the legend of the graphs.



The graphs in Figure 2.4 and 2.5 show the number of incidents per month of 2010 and 2011, respectively. The summer months show more incidents. The dip in February is partly due to the number of days of this month (28). It is difficult to see any real patterns in this overview. The incident load per BT varies between a month or two. The order of the incident load (high to low), as shown in the figure legend, keeps true most of the months. When looking closely an increase can be seen during spring-summer and a lower number of incidents during the winter months.

One recommendation, that may be based on this graph, is scheduling maintenance for vehicles. February is relatively low on incidents, as is August. It may be beneficial to plan preventive maintenance during these months.

2.5.2 Incidents per Week

The data per week is shown in Figure 2.6. The number of incidents per week is shown with a moving average of nine weeks to smooth out the data. The data shown is the combined data of the years 2010 and 2011. The same colours are used per BT as in Figures 2.4 and 2.5. The number of incidents per week show roughly the same distribution with an increase starting around April, a reduction around the last week of August and right after that a small increase, though still lower than the number of incidents during the summer period.

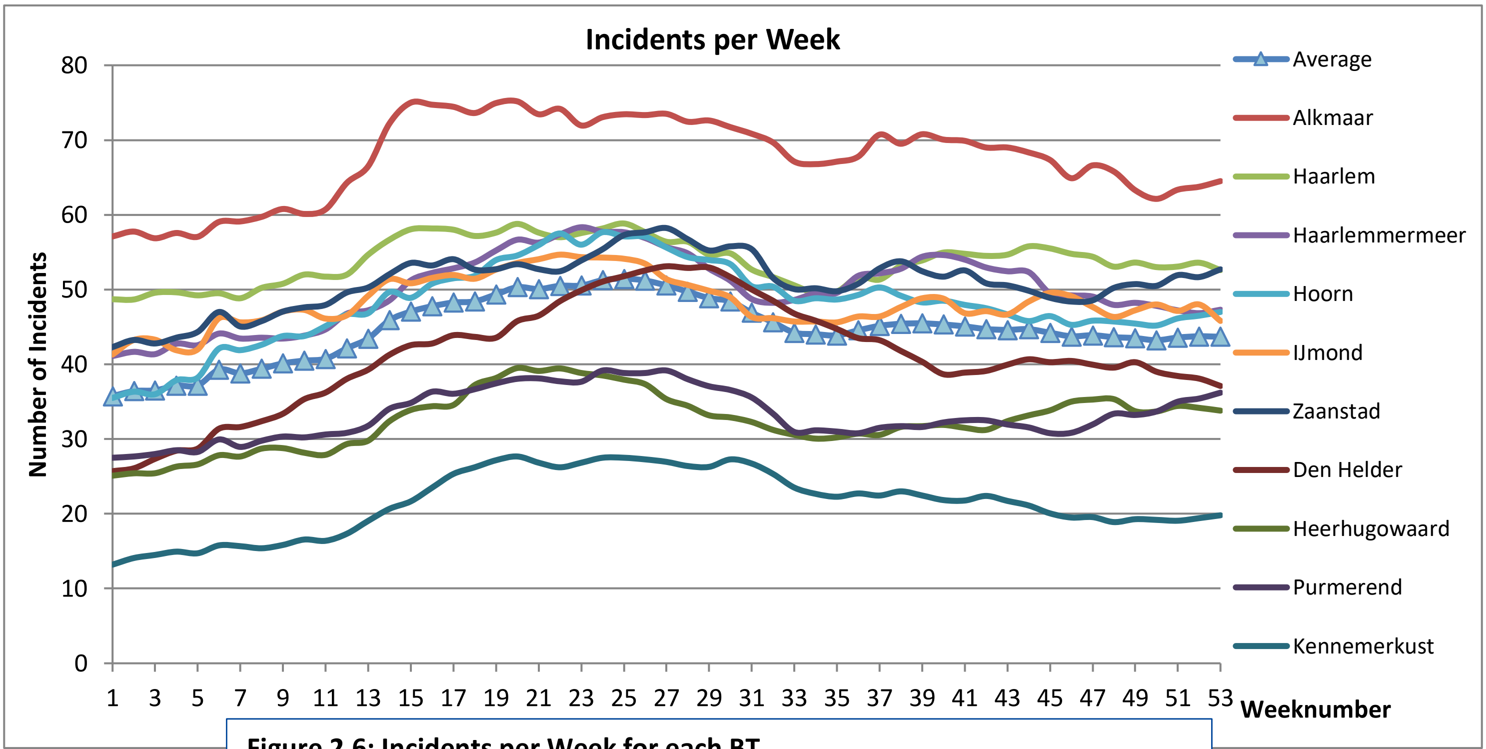


Figure 2.6: Incidents per Week for each BT

The number of incidents per week. A moving average is applied of three weeks.

2.5.3 Incidents per Weekday

When looking at the distribution of incidents for each weekday, there is a clear pattern in that most incidents take place during the afternoon (12:00-18:00), and during the nights on Friday and Saturday. The distribution of incidents is roughly the same for each weekday and weekend. Figure 2.7 depicts the distribution of incidents per day in which the incidents are counted from 2010 and 2011.

The data on incidents shows the mobility requirements for emergencies. The base teams take care of these incidents, sometimes followed-up by other teams if an investigation must take place. The distribution of incidents per weekday follows a similar distribution as found in the data analysis of Muller (2014). This may indicate that differences between the occurrence of incidents is largely similar throughout the Netherlands.

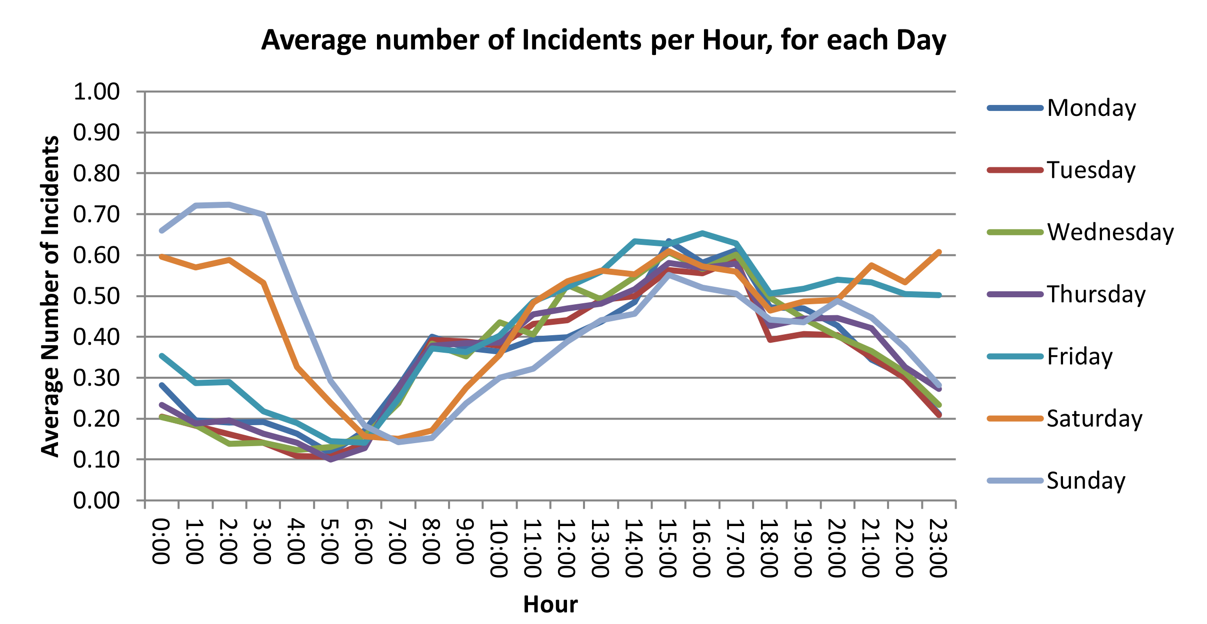


Figure 2.7: Average number of Incidents per Hour

The number of incidents for each hour throughout the week. A moving average is applied of three weeks.

2.6 Aggregated Incident Overview 2015

This data source contains numbers on the number of incidents that took place in each Dutch municipality, distributed across three types of priority. The data shows the number of incidents and, regarding priority one and two, the number of incidents serviced in-time, the number of incidents that occurred in total and the number of incidents of which the time was not measured correctly.

The number of priority one incidents (24,366) is not radically different from the number of incidents for 2010 and 2011 (23,563 and 23,721). The total number of incidents is, priority one, two and three combined, is 173,562. The percentage of priority one incidents is approximately 14%. When extrapolating the number of incidents to 2018, the expected number of incidents is 176,998.

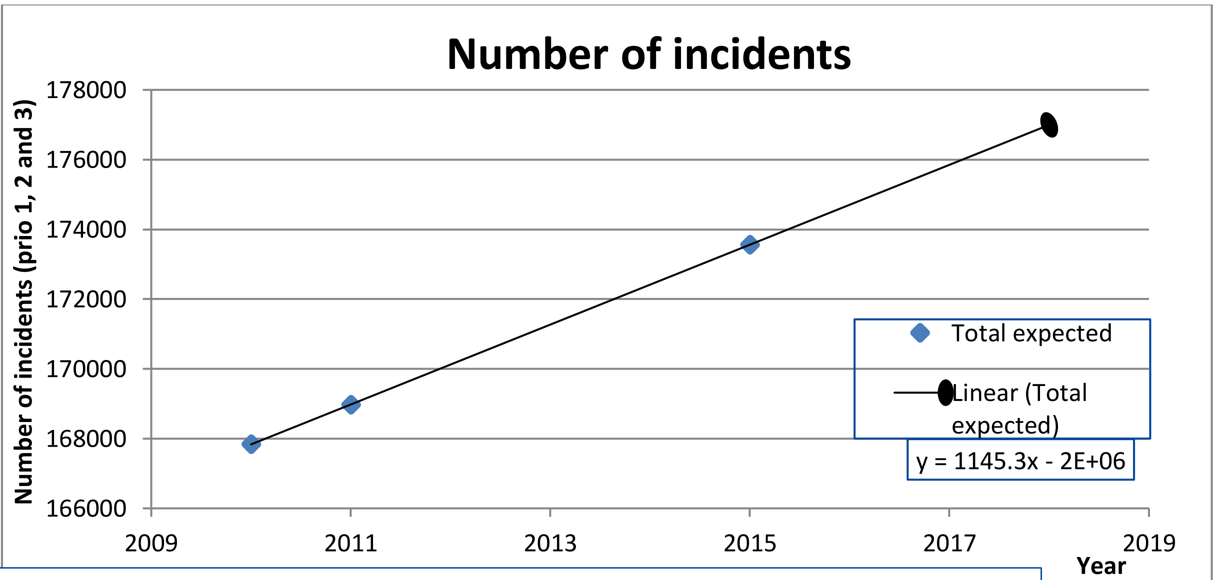


Figure 2.8: Expected number of incidents

This figure shows the expected number of incidents based on the number of priority 1 incidents and percentage of incidents being priority 1 (14%). The expected number of incidents for 2018 is 176,998.

2.7 Conclusion

The Unit has a lot of variety in processes, teams and vehicles. Part of the vehicles is specialized for very specific tasks. The vehicles are divided into four categories: civilian, striped, specialized and covert vehicles. The covert vehicles and specialized vehicles are already assigned to specific processes and employees. There is no question on where these vehicles should be placed. The specialized and covert vehicles play no further part in this research. The striped and civilian vehicles stay part of this research. The striped vehicles are used by the BTs for surveillance, investigations and emergencies. The civilian vehicles are used by all teams to accommodate investigations, meetings, discrete surveillance and mobility for stand-by services.

The goal of the Unit is to maximize the mobility of the Unit. For the striped vehicles, this means that the Unit wants to maximize the percentage of incidents serviced in-time and that the probability of missing out on a civilian vehicle is minimized for all teams equally. The mobility depends on the demand imposed by the teams that want to execute the tasks they are set to perform, by the Police and by law.

Data on the demand is available in the form of incident reports, containing data on the number of incidents that have taken place for priority one, two and three (expected for 2018: 176,998), what part has been responded to in-time (priority one: 89% and priority two 86% in 2013) and an indication on the location of incidents (priority one: first four digits of the zip code, priority two and three: municipality region). The data on civilian vehicles is comprised of one digital key cabinet and vehicle information showing mileages for a part of the vehicles. The data available from the digital key cabinet shows an arrival rate that is Gamma distributed $(\alpha = 2,\ \beta = \ 4.75\ hours)$. The mileages will say something about the demand, indications will be skewed because some teams use the vehicles mostly for small rides, while others use the vehicles to cover great distances throughout the day. In addition, the teams are reorganized causing previous demand indications to be skewed because tasks and teams will be reorganized. Any data required that is not part of this analysis will have to be extrapolated and/or estimated.

3. Literature Search

This chapter is about the literature search. The literature search will mainly focus on two themes. 1) How to distribute emergency vehicles. 2) How to distribute and share vehicles among the teams and locations. At the end of the chapter the following research questions should be answered:

4. Which methods can be used to distribute emergency vehicles?
5. What can be the effects of vehicle sharing for the vehicle usage?

3.1 Distributing Emergency Vehicles

This section deals with question four, finding distribution methods for emergency vehicles. The distribution of the emergency vehicles should provide a robust basis on which the Unit is able to assign vehicles to the ten BTs. The goal of the Unit is to maximize the expected number of on-time responses to incidents.

4. Which methods can be used to distribute emergency vehicles?

A lot of research has been done on the topic of emergency vehicle distributions. Different models have evolved over time to cater different scenarios and specifics of various emergency vehicle allocation problems. A summary of some of these models will be given below. The summary will show the development of models, how they are linked and why adaptions were made. This should provide a good enough basis on which to decide the model used to distribute the vehicle for the Unit.

3.1.1 Minimal coverage

One of the earlier models is proposed by Toregas et al (1971). They introduce the Location Set Covering Problem (LSCP), which aims at finding the minimal number of vehicles required to cover a certain area or a certain set of nodes. This model provides a lower bound on the number of vehicles required to cover a set of locations. The LSCP is widely used as a basis for emergency vehicle distribution upon which extensions and/or improvements are made to satisfy additional needs.

LSCP goal function:

$$Min \sum_{i \in I} y_i \quad [1]$$

Subject to:

$$\sum_{i \in I} a_{ij} y_i \geq 1 \quad \forall\, j \in J \quad [2]$$
$$y_i \in \{0,1\} \quad \forall\, i \in I \quad [3]$$

The goal function [1] aims to minimize the total number of vehicles. A vehicle is located at node i if $y_i = 1$, if no vehicle is present then $y_i = 0$, y_i may only take on values of $\{0,1\}$[3]. Each node j has to be covered. A node j can be reached from node i when $a_{ij} = 1$, which is enforced by restriction [2]. The LSCP gives a lower bound to the minimum number of emergency vehicles, should all nodes be within a specified reach.

3.1.2 Maximal coverage with limited resources

One of the downfalls to the LSCP is that it only gives a lower bound, a minimal number of emergency vehicles. It may be the case that the number of resources to be assigned is limited. Church and

Revelle (1974) propose a slightly different model in which the goal is to find the maximum coverage given a fixed number of facilities, the Maximal Covering Location Problem (MCLP).

MCLP goal function:

$$Max \sum_{i \in I} d_i y_i \quad [4]$$

Subject to:

$$y_i \leq \sum_{j \in I} a_{ij} x_j \qquad \forall\, i\, \in I \quad [5]$$
$$y_i\, \in \{0, 1\}, x_j \in \{0, 1\} \quad \forall\, i\, \in I \quad [6]$$

The goal function [4] seeks to maximize the demand over all nodes by only counting the demand (d_i) when the node is covered. A node is covered when $y_i = 1$, it is not covered when $y_i = 0$ [6]. The first restriction [5] makes sure only nodes that are covered are added to the goal function. The parameter a_{ij} is a Table where $a_{ij} = 1$ if node i is covered by node j, otherwise $a_{ij} = 0$ [6]. The number of facilities located at any node is given by x_j. The MCLP makes it easier to rein in the total costs and provides an optimal solution with restricted resources available.

3.1.3 Multi coverage

An important weakness of the two previous models is that all demand is assumed to be met when one vehicle or facility is present to cover a node. In reality this is not always the case. It may be that more than one incident happens at the same time. Should this happen, the aforementioned models are not equipped to deal with that. Some models were developed to tackle this problem and to provide a more robust solution. For example, the Double Standard Model (DSM) (Gendrau, Laporte, & Semet, 1997) and the Backup Coverage Problems (BACOP1 and BACOP2) (Hogan & ReVelle, 1986) in which locations are covered twice. In the BACOP models, there are multiple coverage objectives. For BACOP1, the first objective is similar to the LSCP, to find the minimal number of vehicles to cover a certain area. In addition, a secondary objective is in place. This secondary objective tries to maximize the demand covered by a fixed number of vehicles, which is similar to the MCLP. In this secondary objective it is not necessary to cover each location. For BACOP2, it is recognized that the addition of a second vehicle on the same or near the same location, my lead to an increased coverage of demand overall. This may be the case in a region where some locations have a very high demand, whereas others have very little demand. The DSM aims to maximize the double coverage. Special input parameters for the model are $radius_1$, $radius_2$ and $\propto$. The $radius_1$ determines the effective radius of the first vehicle which covers a node. The $\propto$ shows the part of the total demand which should be reached within $radius_1$. Any node first has to be covered by a vehicle within $radius_1$. The double coverage vehicles use $radius_2$.

3.1.4 Maximal demand coverage

At times it may even be the case that more than two incidents occur at the same time. When these situations occur, it may be that even the backup-models will not be able to provide a suitable answer. When the focus is to maximize the number of incidents serviced in-time, it may become favourable to assign multiple vehicles to a single, high intensity node rather than assigning vehicles to multiple, low intensity nodes. The Maximal Expected Covering Location Problem (MEXCLP) of Daskin (1983) focusses on achieving the maximal service with limited resources. Compared to the LSCP, the number of vehicles is fixed, changing the decision from trying to minimize the number of vehicles to maximizing the incident coverage.

MEXCLP goal function:

$$Max \sum_{k \in N} \sum_{j \in M} w_j \, h_k y_{jk} \quad [7]$$

Subject to:

$$\sum_{j \in M} y_{jk} - \sum_{i \in N} X_i a_{ki} \leq 0 \quad \forall\, k \in N \quad [8]$$
$$\sum_{i \in N} X_i \leq M \quad [9]$$
$$y_{jk} \in \{0, 1\} \quad \forall\, j \in M \; and \; k \in N \quad [10]$$
$$X_i \in \{0, 1 \ldots, M\} \quad \forall\, i \in N \quad [11]$$

The goal function aims to maximize the expected demand from each location h_k[7]. There are N locations available. The number of facilities allocated to a location is given by X_i. The possible locations a facility can cover is given by table a_{ki}, where $a_{ki} = 1$ if a facility at location i is able to facilitate demand at location k, otherwise $a_{ki} = 0$.Demand may be covered multiple times, $y_{jk} = 1$ if at least j facilities cover location k, otherwise $y_{jk} = 0$. The additional coverage a facility is able to provide is given by w_j. $w_j = (1-p)P^{j-1}, j = 1, \ldots, M$. The value p is the busy probability, indicating the probability that a facility is busy facilitating demand, and not being able to facilitate demand occurring at the same time. In this case another facility is able to facilitate the demand. The probability that the second facility will facilitate the demand is $w_2 = (1-p)p$, the probability that the first facility is busy, times the probability that the second facility is not busy.

3.1.5 Multi-response coverage

Batta and Mannur made an adaptation to the LSCP which allows for the requirement of multiple vehicles serving the same incident, a Multi-Response Maximal Covering Location Problem (MRMCLP) (Batta & Mannur, 1990). The model divides the incidents at a node to incidents requiring a set number of vehicles. The goal function aims at maximizing the weighted coverage of demand for each location and required number of vehicles. Each combination of location and number has a weight added that indicates the importance of that combination. The method provides the opportunity to distinguish between types of incidents requiring more than one vehicle. In addition, may be used to model instances in which multiple incidents occur at the same time, requiring multiple vehicles at once.

3.1.6 Time dependent travel times

Besides taking multiple vehicles into account, there are also models which consider differences in travel times, such as the multi-period DSM, or mDSM (Schmid & Doerner, 2010) and the Time dependent MEXCLP, or TIMEXCLP (Repede & Bernando, 1994). It may occur that during some periods of the day, congestion is such that the coverage of a vehicle changes. With changes in coverage, it may be necessary to relocate vehicles in order to maintain the desired coverage. The adapted models work by defining periods in which the travel times are different and by solving the DSM for each period at once.

There are also dynamic models in which the coverage is recalculated after a vehicle is dispatched to service an incident. However, since the goal of this research is allocating vehicles for a period of a year, dynamic relocation is out of scope.

3.1.7 Comparing the models to the case

The goal of the distribution is to allocate vehicles to locations to cover the demand as best as possible on a yearly basis. The number of vehicles is fixed, the goal should focus on achieving the maximum coverage instead of minimal coverage. Demand may occur with multiple incidents happening at the same time. There has been a timeframe of one hour at which eight incidents had to be serviced at the same time for one BT. Models with single or double coverage are not enough. All BTs follow a similar intensity throughout time, this makes it less relevant to look at differences in driving times and coverages across periods. Therefore, the Daskin model fits the presented problem best and the MEXCLP will be used to distribute the emergency vehicles.

3.2 Distributing Vehicles across Teams

Other vehicles which have to be distributed and assigned are in the group of civilian vehicles. These vehicles can be used by any team/Unit employee for regular movement, transport and stand-by services. The Unit considers a sharing system in order to maximize the use of civilian vehicles, make the vehicles readily available for any employee and to minimize the chance for any employee of missing out on a vehicle when they need one. This section seeks to answer question five:

5. What can be the effects of vehicle sharing for the vehicle usage?

The section will start with several examples of shared vehicle systems. Following that the possible effects of pooling will be investigated.

3.2.1 Shared Vehicle Systems

A shared vehicle system (SVS) may provide the Unit with more flexibility. There already is an SVS in place within most teams, however, the Unit would like to look into options of sharing between teams. Currently, teams have team cars, effectively sharing the cars within the team. The idea is to make vehicles available not only to a team, but to the entire Unit.

The idea of sharing vehicles with a multitude of users is not a new idea. As early as the 1940's there have been plans for vehicle sharing systems (Shaheen, Cohen, & Chung, North American Carsharing: A Ten-Year Retrospective, 2010). Even though not all projects were successful, the number of users of pooled vehicles has risen between 1988 and 2006 exponentially (Shaheen & Cohen, 2007). Some examples of companies who have created vehicle sharing systems are: Enterprise CarShare[12], ZipCar[13], EVO Car Share[14], Modo[15], Greenwheels[16], ConnectCar[17], MyWheels[18], Car2Go[19] and MobilityMixx[20]. These companies maintain a relatively simple system which applies to the users. All

[12] https://www.enterprisecarshare.com/us/en/home.html
[13] http://www.zipcar.com
[14] https://evo.ca
[15] http://www.modo.coop
[16] https://www.greenwheels.com/nl
[17] http://www.connectcar.nl
[18] https://mywheels.nl
[19] https://www.car2go.com/en/vancouver
[20] http://www.mobilitymixx.nl

mentioned companies use four or more of the following six steps: The starting point is vehicle reservation (1), upon pick-up the vehicle can be accessed using a card or phone (2), before driving away the vehicle has to be inspected (3), when the tank reaches a fuel gage of a quarter or less the user should fuel up on the expenses of the company (4), if necessary and possible the use of the car may be extended (5) and upon returning, the vehicle should be left in a decent state. The companies providing these services differ in company owned cars or being a middle-man in car sharing between individuals. The sharing of vehicles is available for individuals, other companies and governments. There are in fact several government agencies who use a vehicle sharing system. An example is Rijkswaterstaat, which makes use of the services of MobilityMixx. In this form of a pool system, users have a personal card with which they can access vehicles or use public transportation[21].

3.2.2 Effects of a pool system

The expectation is that the creation of a pool system ensures that vehicles can be used more efficiently and reduces the probability of missing out on transportation. The pool system is based on the idea that when vehicles will be shared amongst a larger group of users, the use of the capacity will be more efficient due to cars, which would otherwise stand still, being available for other users (Dijk & Sluis, 2004) and (Dijk & Sluis, 2009). Cars that would currently remain parked, will be available for other teams when they require transportation.

To get an idea of the workings of a pool system, an analogy can be made with queueing models. In translation to the model, vehicles can be seen as servers, employees as customers and rides as customer orders. In Figure 3.1 a schematic view of a typical queuing model is given. The arrival intensity of the demand, rides required by the team, is indicated by λ on the IN side. The demand comes in the form of employees/customers having to execute a ride. When a vehicle is readily available, demand can be processed immediately. The duration of the ride is indicated by μ. When no vehicle is available a queue is created, existing out of employees/customers that have to wait for a vehicle/server to become available.

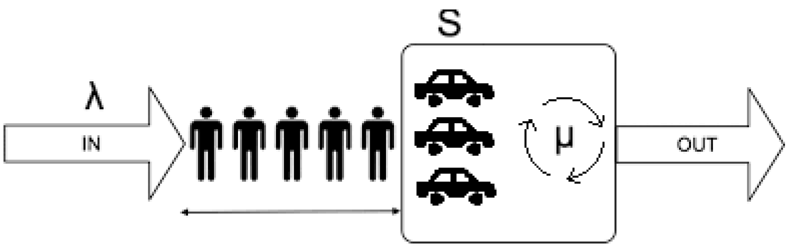


Figure 3.1: Queueing model for vehicle usage

This figure shows a queueing model which represents the vehicle usage of a team. An employee has to go on a ride and arrives with arrival rate λ. The number of vehicles present/fleet size is given by S and the expected duration of the ride is μ.

By creating a pool of vehicles, vehicles assigned to different teams are combined to form a single, expanded vehicle 'pool' for all teams (T): $S_{Location} = \sum_{team \in T} S_{team}$. The arrival intensity of 'customers' now equals the sum of both teams: $\lambda_{Location} = \sum_{team \in T} \lambda_{team}$. A visualization of this pool system is given in Figure 3.2.

[21] A meeting was held with MobilityMixx in order to look at options for the Unit and to gain insight in the workings of a pool system.

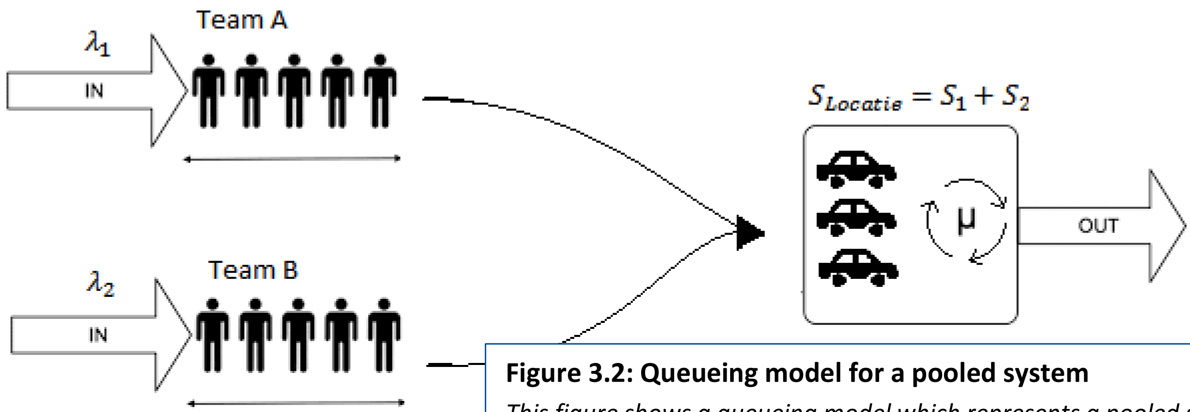


Figure 3.2: Queueing model for a pooled system
This figure shows a queueing model which represents a pooled system for teams A and B. As in Figure 3.1, an employee has to go on a ride with arrival rate λ_t. The employee gets a vehicle from $S_{Locatie}$, that is fleet consisting of the vehicles of both teams combined. The expected duration of the ride is μ, also a combined duration of both teams.

The combined arrivals of both teams mean that also the variation of arrivals is combined. Employees of both teams may now benefit from the combined fleet, as long as any of the vehicles is available, an employee is able to go immediately.

3.2.3 Queueing models

The queues described above can be evaluated by a queueing model (Stzrik & Heszberger, 2012), (Winston, 2004) and (Zijm, 2000). Queueing models are denoted using Kendall's notation. The arrival and service times are expected to be exponentially distributed. There is a limited number of employees for each queue whether it is comprised on one or multiple teams, and thus there is a maximum number of customers for each queue considered. The main question of this research is in the number of vehicles, servers, assigned to each queue. The proposed queueing models from Figure 3.1 can be denoted as $M/M/c/K$. The first M indicates exponential arrival times. The second M indicates exponentially distributed service times. The c denotes the number of servers that simultaneously service demand. The K stands for the maximum number of customers in the queueing system. The fact that there is a maximum number of customers to the system makes sure that there is a maximum number of states the queueing model can take, there can be zero, one, two and up to K customers in the system at once. The state probabilities are defined using the following formulas. The subscript next to π indicates the number of customers in the system.

$$\pi_i = \begin{Bmatrix} if\ S \geq i > k\ then & \dfrac{\lambda * \pi_{i-1}}{c * \mu} \\ if\ i \leq k\ then & \dfrac{\lambda \pi_{i-1}}{j * \mu} \end{Bmatrix} \qquad \forall\, i \qquad [9]$$

$$\pi_0 = \frac{1}{\sum_{n=0}^{n=S-1-c} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} + \frac{\frac{\lambda}{\mu}^S}{(S-c)!} * \frac{1 - \frac{\lambda}{\mu}^{S-c+1}}{1 - \frac{\lambda}{\mu}}} \qquad [10]$$

$$\sum_{i=1}^{i=S} \pi_i + \pi_0 = 1 \qquad [11]$$

Indices:

$$i = 1, 2, \dots I: States$$

Parameters:

$$\lambda: Arrival\ rate\ of\ employees\ requiring\ a\ vehicle$$
$$\mu: Service\ rate\ of\ employees\ when\ using\ a\ vehicle$$
$$S: Maximum\ number\ of\ customers\ for\ the\ queue$$
$$j: \#\ of\ employees\ requiring\ a\ vehicle\ at\ the\ same\ time$$

Variables:

$$c: \#\ of\ vehicles\ assigned\ to\ the\ queue$$
$$\pi_i: Probability\ of\ being\ in\ State\ i, having\ i\ customers\ in\ the\ system$$
$$\pi_0: Probability\ of\ being\ in\ State\ 0$$

The performance the Unit is interested in, is the probability of having to wait. Someone has to wait when there are no vehicles readily available, that is when the number of simultaneous customers in the system is bigger than the number of servers, vehicles, assigned to the queue:

$$P(Wait) = \sum_{i=c+1}^{S} \pi_i \qquad [12]$$

Besides to the probability of having to wait, other data is available when analysing queues such as the expected waiting time. The expected waiting time may indicate the impact or severity of having to wait. For example, the expected waiting time may be less than a minute, in which case having to wait may not be that big of a deal.

3.3 Conclusion

This chapter focussed on finding ways of distributing the vehicles in existing theory. With regard to the **emergency vehicles**, several methods were discussed, considering different performance measures and/or using different parameters as a basis. Considering the goals and parameters of the Unit, the best fit appeared to be the model by Daskin, trying to maximize the demand coverage across multiple demand points, while considering that vehicles are not always available.

Civilian vehicles should be distributed across teams or locations and several people within the Unit wonder whether dedicated standby-service vehicles are actually required. The use of the vehicles may be approximated using a queueing model. The main concern of the Unit is to minimize the probability of having to wait. This can be analysed using the queueing model: $M/M/c/K$. This model assumes an independent and identically distributed arrival rate and service time, with a number of c vehicles available to the queue and a maximum of K customers.

4. Vehicle distribution

This chapter focusses on the distribution of the vehicles. Based on the data and literature, models to distribute the vehicles are proposed. The following questions will be answered:

6. Which models are used to distribute the vehicles of the Unit?
7. Which model configuration fits the main question best?

The chapter will first focus on the emergency vehicles and then on the civilian vehicles. This is done due to the difference of the properties and use of both vehicle types. Most of the times, usage of either vehicle is not interchangeable. There are specific rules and regulations that apply to emergency vehicles. which makes this vehicle unsuitable for the general movement and investigative tasks for which the civilian vehicles are used. There will be a slight error when making a separate distribution for both types of vehicles, which is the case when both vehicles could be used for the same task. This may be the case when officers of a BT want to investigate a location. They could travel with both types of vehicles. However, often there are good reasons to choose either one of these vehicles, such as visibility and urgency of the situation, thus the overlap should be minimal.

4.1 Available information and goals

There are several data sources, which have been discussed in Chapter 2. These data sources are available:

- Interviews performed with each team
- Summary of BT data (Incidents, Population, Area size and FTE´s)
- List of vehicles in the current fleet
- Digital key cabinet data
- Reported incidents

These are the goals and plans of the Unit, also discussed in Chapter 2:

- Maximize on-time response-times
- Maximize visibility and prevention of crimes
- Maximize suspect ratios
- Maximize the overall public opinion of feeling safe
- Equal distribution of civilian vehicles/equal chances of missing out on a civilian vehicle

With this information, a distribution has to be made that is based on the information from the data sources and should be linked to the list of goals.

When reviewing the list of goals, one of the goals does not match with some of the earlier research. The goal to *maximize visibility and prevention of crimes*, which is related to the surveillance tasks of the BTs may not have an effect at all. Some research suggests that the use of preventive surveillance is not linked to a reduction of the crime rate nor an increase in the safety feeling of the public (Kelling, Pate, Dieckman, & Bronw, 1974). There is still a good reason to perform surveillance. Surveillance helps the police to see what is going on in neighbourhoods quickly and to get some visual feedback from the streets. Because there is no clear link between surveillance and any of the goals mentioned, the use of surveillance as a way of achieving the Unit's goals will be ignored. This does not mean that surveillance will not be considered. The surveillance will take place as a means of providing the right coverage of an area. Vehicles surveilling an area can respond quickly when an incident occurs. Thereby, surveillance will be used and add up to an increased performance. Other effects of surveillance are not considered.

Exploring the goals further, a distinction can be made between the goals for civilian vehicles and emergency vehicles. The *on-time response-time* goal only applies to the emergency vehicles, because this is a specific task for emergency vehicles and these vehicles are designed for this. The goal of *equal distribution of vehicles/chance of missing out on a vehicle* only applies to civilian vehicles. This goal has been added by the management of the Unit. When sharing vehicles within the Unit or a team (less vehicles than employees), there will be a moment at which there is a vehicle shortage, for whatever reason. Furthermore, all the jobs that must be done are of equal importance and thus every team should have an equal availability of civilian vehicles. Usage of vehicles will therefor follow a first come first serve (FCFS) principle.

4.2 Emergency vehicle distribution

The emergency vehicle distribution should relate to the emergency handling of the police. To this end the emergency vehicles must be distributed across the Unit and be assigned to the BTs. To provide a distribution that maximizes the number of on-time response-times, a distribution will be made based on the MEXCLP. Some adaptations will be made to fit the Unit's needs better. The biggest change will be that three coverage tables will be used in order to determine the coverage of the three incident priority types. When a vehicle is placed at a location, the response-time restrictions for the incident types are different for each incident: priority 1 within 15 minutes, priority 2 within 30 minutes and priority 3 without a time limit.

4.2.1 Distribution model

The model used to distribute emergency vehicles is based on the MEXCLP model of Daskin (Daskin, 1983). This model is used to maximize the expected coverage. For this particular case the model will be adjusted to suit the differences in coverage for the priority types. First the model will be presented in full. After that, the model is explained.

MEXCLP goal function:

$$Max \sum_{i \in I} \sum_{k \in K} \sum_{p \in P} d_{ip} w_k y_{ikp} \quad [1]$$

Subject to:

$$\sum_{k \in K} y_{ikp} \leq \sum_{j \in I} x_j a_{ijp} \qquad \forall\, i \in I \; and \; p \in P \qquad [2]$$

$$\sum_{j \in I} x_j \leq V \qquad [3]$$

$$y_{ikp}, a_{ijp} \in \{0, 1\} \qquad \forall\, i \in I, j \in I, k \in K, p \in P \qquad [4]$$

$$x_j \in \{0, 1, \dots V\} \qquad \forall\, j \in I \qquad [5]$$

Indices:

$i = 1, 2, \dots I: Nodes$
$j = 1, 2, \dots I: Nodes$
$k = 1, 2, \dots K: Vehicles$
$p = 1, 2, 3\ (P): Priorities$

Parameters:

d_{ip}: *Demand or weight of each Location*, i, *for each Priority*, p.
$w_k = (1-q)q^{k-1}$: *Probability of demand covered by the* j^{th} *vehicle*.
q: *Busy probability, probability of a vehicle being busy*.
$a_{ijp} = \{0,1\}: \left\{ \frac{1 \text{ if Location } i \text{ is covered from Location } j}{0 \text{ if Location } i \text{ is not covered from Location } j} \text{ for Priority } p \right\}$

Variables:

y_{ikp}: *Whether at least* k *Vehicles are able to cover Demand at Location* i *for Priority* p.
x_j: *The number of Vehicles allocated to Location* j.

Description
The goal function aims to maximize the expected demand from each location for each priority type d_{ip}[1]. Demand can only be covered if the location is covered by at least one vehicle and if the vehicle is not busy. Demand coverage is controlled by constraint [2]. Depending on the number of vehicles assigned to node j, shown by x_j, and the coverage matrix a_{ijp}, nodes can be covered in-time or not. The number of vehicles that cover a location, $\sum_{k \in K} y_{ikp}$, depends on the number of vehicles assigned to the nodes, x_j, and whether those vehicles can reach location i from location j in-time, a_{ijp}. When a node can be reached in-time $a_{ijp} = 1$, otherwise $a_{ijp} = 0$. A distinction is made for each priority type, p, because each priority type maintains a different response-time and therefor a different coverage radius.

The number of vehicles assigned to any location is shown by x_j and limited by constraint [3]. The sum of all assigned vehicles cannot be greater than the number of vehicles available. The variable x_j is the defining variable of the model.

Demand is covered by a vehicle if the vehicle is not occupied. Within the expected horizon in which the demand may take place, vehicles are expected to be busy for a fraction, q, of the time, this is the busy probability. The vehicle will be able to cover demand at reachable location with a probability of $(1-q)$. A second vehicle covering the same location has the same probability of covering this node, but only if the first vehicle is busy, $\left(q * (1-q)\right)$. The k^{th} vehicle will be able to cover demand when $(k-1)$ vehicles are busy, $w_k = (1-q)q^{k-1}$.

4.2.2 Parameters

Coverage matrix
One of the parameters in the MEXCLP model is the coverage matrix. This matrix determines whether a node can be reached or not. In this case it is important to find out whether a node can be reached in-time. A priority one incident is serviced in-time if a vehicle arrives within fifteen minutes of receiving the incident call. Previous research has shown that the dispatch delay time between receiving the call and dispatching a vehicle is about three minutes (Muller, 2014). This leaves 12 minutes for a vehicle to reach a location for priority one incidents and 27 minutes for priority two incidents.

To determine the node locations, a rectangular grid is made of 100*100 nodes, setting 10,000 geographical points to the map. The four corners of the grid are based on the location information of the priority one data. After the initial grid is made, all nodes not falling within the Unit are removed from the grid resulting in 4322 remaining nodes. The remaining nodes are assigned to the BTs. Because of the number of nodes, the assignment to the BTs is done by looking at the closest priority one incident and looking for the BT assigned to that priority. The locations for priority one incidents are used because these provide the most detailed image of the BT locations.

The coverage matrix shows whether a node is able to reach another node in-time. Thus, the matrix consists of a list of nodes vertically and those same nodes again horizontally. The matrix is represented in the model by parameter a_{ij}. $a_{ij} = 1$ if node i can be reached in-time from node j, otherwise $a_{ji} = 0$. Each node has a distinct location, a coordinate. Between two different coordinates there will be a physical distance. To determine the distance between two nodes, the Haversine formula is used (Veness, 2018):

$$Distance = R * \cos^{-1}(\cos(lat_1) * \cos(lat_2) + \sin(lat_1) * \sin(lat_2) * \cos(\Delta long))$$

With R being the earth's radius (6371 km), lat_1 being the latitude value of node i and lat_2 of node j, and $\Delta long$ being the difference between the longitude values of both nodes. If the distance between nodes is equal or smaller than the distance an emergency vehicle is able to cover, the value for the parameter is equal to 1.

Busy probability

The service probability is being used to determine the probability that a vehicle is busy and thus not able to service an incident at any point in-time. The probability is based on the time the vehicles are expected to be busy with servicing incidents and being unavailable due to, for example, maintenance and repairs divided by the total availability of the vehicles of the Unit combined.

The total handling of priority one incidents is based on the handling time of the incidents themselves and the expected travel times. The incident handling time, or expected service duration, is on average 30 minutes (Muller, 2014, pp. 18-19). The expected travel time will be 15 minutes or less. To make sure enough time is reserved for the vehicles to respond, the travel time will be set to the maximum travel time which is 15 minutes. The total expected duration to handle a priority one incident is 45 minutes.

The total handling time of priority two incidents is also based on incident handling time and the expected travel time. The expected incident handling time is the same and the maximum expected travel time is 30 minutes. The total expected handling time for a priority two incident is 60 minutes.

The total handling time of a priority three incident is based on, again, the incident handling time and its maximum travel time. The maximum travel time within each BT from the main location appears to be 30 minutes, with one exception being Den Burg, which can be reached within an hour. The exception is due to the fact that Den Burg can only be reached with the use of a boat/ferry. The Exception will remain an exception. More likely, the average travel time will be less as officers will be able to reach priority three locations at more convenient times. The expected travel time of a priority three incident will be approximated as 30 minutes. The total expected handling time is 60 minutes.

The time required for repairs and maintenance is unclear. No data is present at the moment. Given the use of the vehicles, extensive maintenance can be expected. For the purpose of this research a guess is made that on average each vehicle will require four weeks of maintenance a year.

The number of vehicles is 125 for the entire Unit. This will provide the Unit with a maximum of $125_{vehicles} * 365_{days} * 24_{hours} = 1{,}095{,}000\ servicable\ hours$. The expected number of priority one incidents is 24848 and the expected number of priority two and three incidents is 75341 and 76809 respectively, resulting in a workload of $24{,}848 * 45_{minutes} + 152{,}150 * 60_{minutes} = 170{,}786_{service\ hours}$. If another four weeks of maintenance is added to each vehicle the following busy probability is produced:

$$\frac{170{,}786_{Service\ hours} + 84{,}000_{Maintenance\ hours}}{1{,}095{,}000\ servicable\ hours} \approx 23\%$$

Demand

Demand is based on the data available from the two data sources showing the number of priority one incidents and locations on zip code level and the number of priority two and three incidents on municipality level. The data for these priorities has been allocated by assigned them to the nearest node. Using this method however, causes that large portions of nodes do not have an expected demand and thus do not require coverage. However, this is not realistic, because incidents may not occur at a specific location during one year, but they may occur in the next year. To deal with this, all nodes have been assigned a minimum number of expected incidents. This results in a minimum of one incident for all priority one incidents, 9 for priority two incidents and 27 for priority three incidents. This will create the most contrast for priority one incidents and the least for priority three. This can be justified by the fact that the data for priority one incidents is already the most detailed and that the distribution across the nodes is less important for priority two and three incidents because they can be covered from further away.

4.2.3 Distribution Results

The results of the distribution model can be seen in Table 4.1. The model is executed in AIMMS. The size of the model, containing 4322 nodes, caused some issues when importing the data to the coverage tables. Therefore, the model is divided by ten, into the separate BTs. To combine the data, the model is run for several configurations for each BT. A configuration is the number of assigned vehicles to the BT. The range of configurations differs slightly between the BTs, as not all values are relevant. More vehicles lead to a higher coverage. For low values, the difference in the goal function becomes too large to be relevant. For high values the difference in the goal function is too small to be relevant. The configurations that create optimal coverage in this model are not at the edges of the considered ranges. The distributions and the corresponding coverage results can be seen in Table 4.1.

#Vehicles	Den Helder	Heerhugowaard	Alkmaar	Hoorn	Haarlem	Haarlemmermeer	Kennemerkust	IJmond	Zaanstad	Purmerend
1										
2										
3					24602.97		9698.99	27196.50	29552.01	28611.87
4					24836.30		9791.22	27454.75	29832.28	28900.15
5			49662.20	42656.48	24889.97	30103.89	9812.54	27514.15	29896.75	28969.15
6			49713.74	42702.84	24902.31	30127.39	9817.47	27527.88	29911.57	28988.11
7			49735.89	42720.45	24905.15	30135.80	9818.63	27531.03	29914.98	28993.08
8		49312.83	49747.58	42728.00	24905.80	30138.64	**9818.91**	27531.77	29915.77	28994.94
9	40614.77	49326.43	49753.56	42732.41	**24905.96**	30139.98	9818.97	**27531.94**	**29915.95**	28995.50
10	40626.78	49334.49	49756.85	42734.23	24905.99	30140.50	9818.99	27531.99	29915.99	**28995.79**
11	40634.51	49339.13	49759.04	42735.45	24906.00	30140.77	9819.00	27532.00	29916.00	28995.89
12	40638.68	49341.57	49760.16	42736.13	24906.00	**30140.89**	9819.00		29916.00	28995.95
13	40641.07	49343.44	49760.89	42736.49	24906.00	30140.95			29916.00	28995.98
14	40642.72	49344.41	49761.35	42736.69	24906.00	30140.97			29916.00	28995.99
15	40643.60	49344.93	49761.59	**42736.83**	24906.00	30140.99			29916.00	28995.99
16	40644.13	49345.37	**49761.75**	42736.90		30140.99				28996.00
17	40644.49	49345.59	49761.86	42736.94		30141.00				28996.00
18	40644.68	**49345.74**	49761.91	42736.97		30141.00				28996.00
19	**40644.80**	49345.84	49761.94	42736.98						28996.00
20	40644.88	49345.89	49761.97	42736.99						28996.00
21	40644.93	49345.93								
22	40644.95	49345.95								
23	40644.97	49345.97								
24	40644.98	49345.98								

Table 4.1: MEXCLP Emergency Vehicle configuration results: This table shows the results of the goal function, when evaluating the model for different configurations (BT and # of vehicles available). The chosen configuration combination is highlighted for each BT.

Table 4.1 is used to determine the optimal combination of vehicles assigned to the BTs. The optimization of the vehicle combination is done using the following model:

$$Max\ Z = \ Max \sum\nolimits_{i \in BTs} \sum\nolimits_{j \in AssignedVehicles} D_{ij} y_{ij} \qquad [6]$$

Subject to:

$$\sum\nolimits_{i \in BTs} \sum\nolimits_{j \in AssignedVehicles} y_{ij} * j \leq V \qquad [7]$$

$$\sum\nolimits_{j \in AssignedVehicles} y_{ij} \leq 1 \quad \forall\, i \in BTs \qquad [8]$$

The model aims to maximize the demand covered for all the ten BTs. The combination of configurations should lead to a vehicle distribution that fits the fleet size of the Unit. The maximum number of vehicles to assign to the BTs combined may not exceed the fleet size $V = 125\ vehicles$ [7]. For each BT, only one set of vehicles is allowed [8]. The resulting number of vehicles for each BT is shown in Table 4.2. The total demand covered is nearly 100%. Only one incident is not reached in-time on average.

BT	Den Helder	Heerhugowaard	Alkmaar	Hoorn	Haarlem	Haarlemmermeer	Kennemerkust	Ijmond	Zaanstad	Purmerend
Vehicles	19	18	16	15	9	12	8	9	9	10

Table 4.2: Optimal BT Vehicle configuration: This table shows the optimal number of vehicles assigned to each BT for the MEXCLP model.

Besides Table 4.2, the vehicle allocation can be viewed graphically in Figure 4.1. This figure shows the nodes at which vehicles have been placed, using the distribution model.

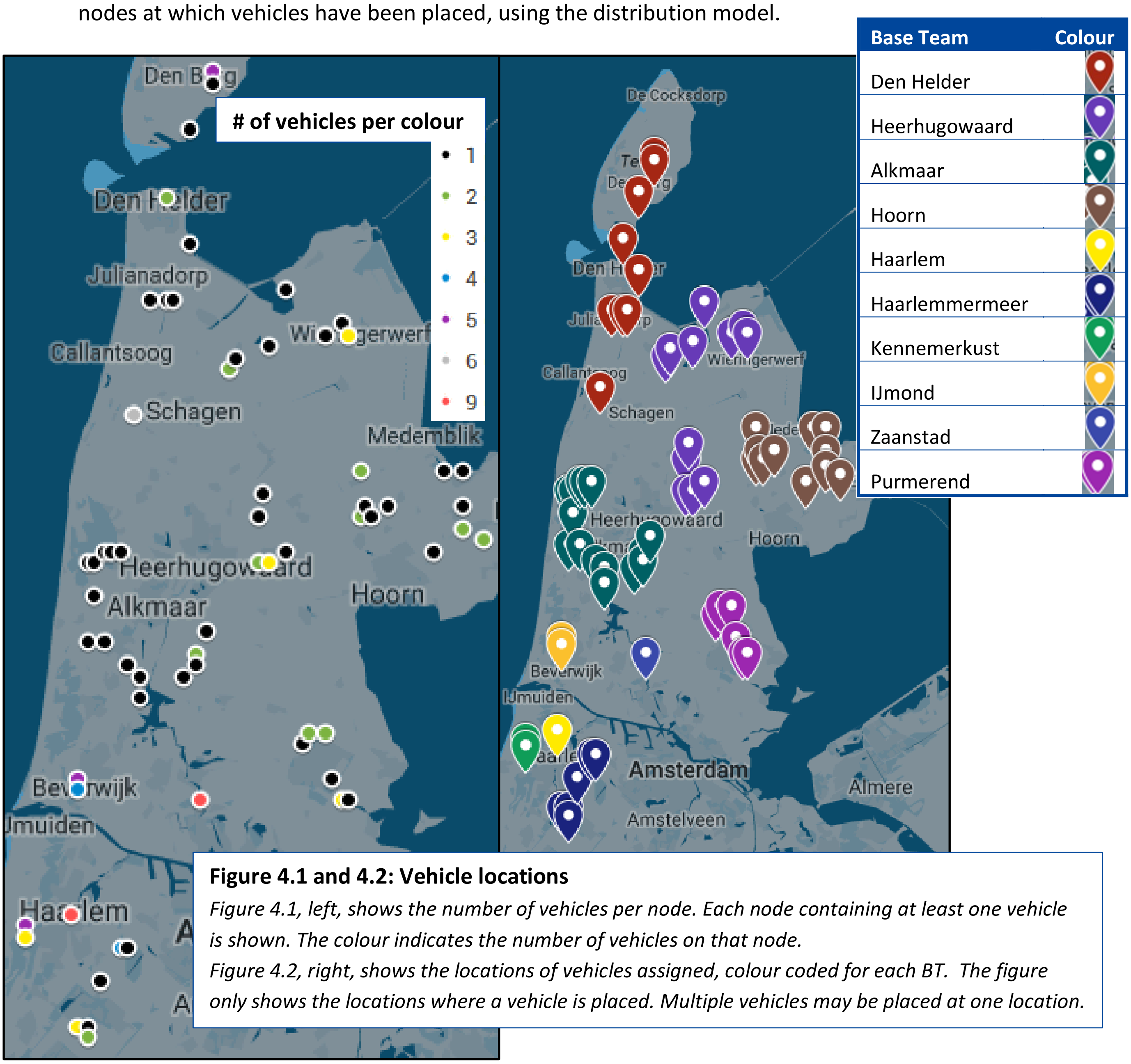


Figure 4.1 and 4.2: Vehicle locations

Figure 4.1, left, shows the number of vehicles per node. Each node containing at least one vehicle is shown. The colour indicates the number of vehicles on that node.

Figure 4.2, right, shows the locations of vehicles assigned, colour coded for each BT. The figure only shows the locations where a vehicle is placed. Multiple vehicles may be placed at one location.

4.2.4 Discussion

The distribution of emergency vehicles covers all of the nodes defined within the Unit. In theory, all nodes can be reached in-time when a priority one incident occurs. Some BTs can even make do with just one location to place the vehicles. The count of expected incidents missed, one for an entire year, seems to suggest that not reaching an incident in-time is more of an exception rather than an expected part of demand. When the real performance is compared to the distribution performance, there is a large gap, distribution coverage is 100% and real coverage is 89% for priority 1 and 86% for priority 2 incidents. It will be interesting to find out where this difference comes from. The distribution only looks at the vehicle availability for an entire year, aggregating data and looking at averages. Incorporating a more realistic process flow and demand changes per hour during the week may create a different view on the vehicle distribution.

4.3 Distribution of Civilian Vehicles

Civilian vehicles are used for general mobility requirements, such as meetings and investigations, and for standby-services. Most teams require the use of civilian vehicles. As discussed in Section 3.3, a pool system is considered. In addition, there is a discussion about vehicles being used for standby-services, whether they should be supplied by the team or by the Unit.

This Section will focus on distributing civilian vehicles to analyse the expected behaviour towards the goals of the Unit. The section starts with defining four scenarios. Using these scenarios, the expected behaviour towards the goals will be analysed using queueing theory.

4.3.1 Distribution scenarios

When defining the distribution of civilian vehicles, the Unit made clear that the main goal should be to minimize the probability of having to miss-out on a vehicle. The probability of having to wait until a vehicle is available. The Unit is considering using the vehicles in a pool system where multiple teams can access the vehicles present at the location. Another item that is frequently heard amongst the teams is to reduce the reservations of vehicles for standby-services. For both considerations the Unit states that all teams should be treated equally.

The distribution of civilian vehicles should be based on the two considerations. First: shared for all teams at a location versus shared within a team at a location and second, to whether to reserve vehicles for standby-services. The basis for the distribution will take place over the following four scenarios, that will be elaborated upon next:

- Scenario 1: Distribution on team level, with separate standby-cars
- Scenario 2: Distribution on team level, incorporating standby demand to teams
- Scenario 3: Distribution on location level, with separate standby-cars
- Scenario 4: Distribution on location level, incorporating standby demand to locations

Scenario one

The first scenario is what most teams would like. In this scenario they have the most direct control over their vehicles and they are provided with vehicles for standby-services. It is like an ideal picture, if there are enough vehicles to satisfy all demand. This option is the least flexible option, since it allocates capacity on the most detailed level of all four scenarios.

Scenario two

The second scenario resembles the current situation best. Teams have vehicles assigned to them, giving them direct control over these vehicles. All demand must be supplied from the assigned vehicles, sharing between teams is not allowed. Vehicles for standby-services are supplied by the team currently responsible.

Scenario three

The third scenario is currently being considered since there are not enough vehicles to support all demand using the first scenario and because uncertainty and unequal treatments arise in the second scenario. Having vehicles on standby for specialized emergencies is a valued concept throughout the Unit. There is no clear consensus however to the extend on which standby-cars should be assigned to stand-by services.

Scenario four

The fourth scenario is expected to provide the most flexible distribution of vehicles. There are some worries that using this method, not all standby-services will have a vehicle at their disposal in case of an emergency. Not having dedicated standby-cars is the capacity opposite of having dedicated cars. This option may not be popular and may gain little acceptance, however it will give an indication on whether freeing capacity from standby-cars will result in a higher service-level. It may provide reasons to prioritize vehicle availability on standby-services.

4.3.2 Distribution model

To distribute the vehicles for the four scenarios, a queueing model is used. The vehicles are assigned to the teams to minimize the average probability of missing out on a vehicle. In addition, the average waiting time is measured as the model outcome to indicate the impact of missing out. Queues are defined for each scenario. A queue consists of a location and one or more teams. Each queue has the following parameters:

- Arrival rate: The average number of rides per hour
- Service rate: The average number of rides a vehicle executes per hour
- FTE: The maximum number of officers that can ride simultaneously

The parameter averages are based on requirements during the day, as this is the most busy and critical time for the civilian vehicle usage. Each queue is assumed to have an exponential arrival and service time. This assumption is based on the data from the Key-Cabinet, indicating exponentially distributed arrival times. This leads to the use of the following queueing model: M/M/c/K. Poisson arrival and service times, a server capacity of c and a customer capacity of s.

Next to the Queues for the locations and teams there are the Standby-services that are serviced separately for scenario 1 and 3 or incorporated into the demand of the teams and locations for scenario 2 and 4. In the case of scenario 1 and 3 there will be no waiting time and no chances of missing out because of the vehicles dedicated to the standby-services. When the demand is incorporated, the probability of missing out will be the same as for the regular demand. One standby-service may be serviced by multiple teams. The demand increase will be added to the involved teams based on the FTE value of the team/location. The resulting performance indicators will be a weighted average using these same weights.

4.3.2.1 Creating Queues

All queues use the same input parameters and the same queueing model. Based on the scenario, one or more queues are aggregated into one queue. An important part of the queues are the state probabilities with which the probability of missing out on a vehicle can be calculated. Each state is defined as the number of customers, or ride demand in this case. The maximum number of simultaneous demand is set equal to the number of FTEs for that queue. In the case of scenario 1 and 2, this is equal to the number of FTEs per team. In the case of scenario 3 and 4, this is equal to the number of FTE allocated at a location. The queues have a finite number of possibilities which makes it possible to get a reasonable estimation of the state probabilities. The states within a queue are connected in such a way that the sum of the state probabilities is equal to the number 1. The state probabilities are defined using the following formulas.

$$\pi_{k,0} = \frac{1}{\sum_{n=0}^{n=S_k-1-c_k} \frac{\left(\frac{\lambda_k}{\mu_k}\right)^n}{n!} + \frac{\frac{\lambda_k}{\mu_k}^{S_k}}{(S_k - c_k)!} * \frac{1-\frac{\lambda_k}{\mu_k}^{S_k-c_k+1}}{1-\frac{\lambda_k}{\mu_k}}} \qquad \forall\, k \qquad [9]$$

$$\sum_{i=1}^{i=s_k} \pi_{k,i} + \pi_{k,0} = 1 \qquad \forall\, k \qquad [10]$$

$$\pi_{k,i} = \begin{Bmatrix} if\ i \leq c_k\ then\ \frac{\lambda_k \pi_{k,i-1}}{j_k \mu_k} \\ if\, s_k \geq i > c_k\ then\ \frac{\lambda_k \pi_{k,i-1}}{c_k \mu_k} \\ if\ i > s_k\ then\ 0 \end{Bmatrix} \qquad \forall\, k, i \qquad [11]$$

Indices:

$$k = 1, 2, \dots K: Queues$$
$$i = 1, 2, \dots I: States$$

Parameters:

$\lambda_k: Arrival\ rate\ of\ employees\ requiring\ a\ vehicle$
$\mu_k: Service\ rate\ of\ employees\ when\ using\ a\ vehicle$
$s_k: Maximum\ number\ of\ customers\ for\ the\ queue, given\ in\ FTE$
$j_k: \#\ of\ employees\ requiring\ a\ vehicle\ at\ the\ same\ time$

Variables:

$c_k: \#\ of\ vehicles\ assigned\ to\ queue\ k$
$\pi_{k,i}: Probability\ of\ being\ in\ State\ i\ for\ queue\ k$
$\pi_{k,0}: Probability\ of\ being\ in\ State\ 0\ for\ queue\ k$

Because some of the queues have many states and because some queues have a high arrival to service ratio $\left(\frac{\lambda}{\mu}\right)$, this leads to some very low values of π_0 (e.g. $1 * 10^{-26}$), causing difficulties with solving the sum of states to 1. To start with a stable set of queues, the starting value of the number of servers, assigned civilian vehicles c, is set to the minimum number causing that $\left(\frac{\lambda}{c\mu}\right) \leq 1$.

4.3.2.2 Adding Vehicles

After setting up the queues, a script iteratively adds a vehicle to the queue having the highest probability of having to wait for a vehicle. This method serves the Unit best, since all employees are to be treated equal. The iteration stops when all

When queues are aggregated the arrival-rate can be summed up for the queues that are combined. The service-rate can be recalculated as the weighted average of the service rates that are being combined. The service rate of a combined queue will be determined by the service-rates of the queues the combined one is formed. The part of arrived jobs, or rides in this case, depends on the arrival of rides. The weights of the service rates to be combined into a single one will be $\frac{\lambda_k}{\lambda_{combined}}$.

4.3.3 Distribution results

After applying the above distribution method, the vehicles are placed at locations and/or teams depending on the scenario. The resulting distributions and waiting times can be found in Appendix B, the appendix is used due to the size of the tables, 80 rows for scenarios 1 and 2, 23 rows for scenarios 3 and 4. The aggregated results can be found in Table 4.3. The results show the probability of having to wait for each scenario and the expected waiting time in hours.

Table 4.3: Distribution Scenario Results, aggregated: This table shows the aggregated results of distributing the civilian vehicles across the teams and locations for each of the four scenarios discussed before.

Scenario	P(Wait)	E(Wait) (hours)
1	8.86%	0.219
2	5.14%	0.063
3	0.30%	0.002
4	0.05%	0.000

The probability to miss out on a vehicle and as a consequence having to wait until one is available, diminishes when there is more sharing amongst the teams. This shows when comparing scenario 1 to 3 and 2 to 4. These two comparisons show what happens when vehicles are shared between teams at the same location. A similar trend can be seen when freeing capacity from dedicated standby-service vehicles, comparing 1 to 2 and 3 to 4. Every scenario comparison, points to the direction that more sharing of vehicles, leads to lower waiting probabilities.

4.3.4 Discussion

More sharing leads to lower waiting probabilities. This may well be true for the general use of vehicles. However, this might not be desirable for standby-services as these are used to provide employees transportation needs in case their specialism is required within a specified time period. In general, the frequency of usage is less for standby-services, but the impact may be bigger when compared to regular usage.

4.4 Conclusion

The distribution models provided a method of distributing the vehicles across the Unit. The results are quite favourable. Emergency vehicles are expected to have be late for at most one incident for the entire year and the civilian vehicles can be distributed in such a way the there is a very low chance, 0.05%, of having to wait and if that is the case, the average waiting time should be less than four seconds.

The assumption is that the distribution methods are adequate in capturing the needs and requirements of the Unit. Based on the available information a guess has been made to the needs of most of the teams. The models provide, based on averages, an expected performance when placing the vehicles at certain locations. A question that may arise is how the teams respond to such an allocation of resources. The dynamics of processes that occur on a daily basis may have undesired side effects, even though the aggregated results may not indicate such behaviour. To evaluate the response of the teams to the distribution provided here, a simulation study is performed. A simulation study will allow the incorporation of process flows, the way decisions are made and jobs are conducted. The simulation study is performed next, in Chapter 5.

5. Simulation

This chapter focusses on the simulation studies of for the emergency and civilian vehicles. The studies will provide further insight into the way the team performance may react to the distributions provided in Chapter 4. This chapter should answer the following two questions:

8. With which model/within which boundaries will the simulation study take place?
9. What is the expected performance of the tested scenarios?

Using simulation, it is possible to evaluate the performance of the provided distributions applying the decisions and workflows of the teams when using the vehicles. Using simulation, it is possible to verify whether the distributions provided in the previous chapter, are adequate in allocating the vehicles.

This chapter will handle both the emergency and the civilian vehicle simulation studies. For each model, the following structure will be followed. The first section will be the goals of the model. This is followed by the flowchart showing the general process and scope. A description of the flowchart is given after that, describing the model, level of detail, scope and assumptions made.

5.1 Simulation of Emergency Vehicles

The model for emergency vehicles focusses on the use of emergency vehicles with regard to incidents/emergencies. The use of emergency vehicles is mainly determined by reported incidents and the use for surveillance. The incidents are called in at the “surveillance room”. This centre has a real-time overview of all vehicles and their status, indicating what each vehicle is doing. When an incident is called in they decide which vehicle should be dispatched to handle the incident. Generally, the closest available vehicle will be dispatched to take care of the incident. This may not be the vehicle that is closest since some vehicles may already be busy handling other incidents. Another case may be that the incident needs to be serviced in-time, while there are no free vehicles within range. A vehicle may be called upon that is already handling a lower priority incident, causing the lower priority incident to be interrupted. The decision model is incorporated into two flowcharts, Figure 5.1 and 5.2, that will be used to determine the performance of the distribution provided in Chapter 4. To provide a point of reference to the results of the simulation, two alternative distributions will be provided. One model will place each vehicle at a random location and another model will place all vehicles at the main address of each BT. The random distribution provides a null performance. The address distribution will show what happens to incident response times when all officers stay within at the bureau and only head out when called upon. This distribution is relevant because part of the tasks performed by the officers take place at the desk, thus it may be worthwhile to see the performance when all officers stay inside.

5.1.1 Goals

The goal of the emergency vehicles is primarily to service incidents in-time, within fifteen minutes for priority one incidents and within 30 minutes for priority two incidents. As shown in the goals of the Unit, the on-time response-times for incidents is an important measure of the Unit’s performance. These goals formed the basis of the emergency vehicle distribution in section 4.2 and these goals will also be measured in this simulation. The total list of performance indicators will be:

- Percentage of in-time priority one incidents
- Percentage of in-time priority two incidents

- Demand handled by a vehicle outside the BT region where the incident occurred
- Waiting time when incidents are interrupted for higher priority incidents

5.1.2 Flowchart

All incidents that occur in the Unit are centralised at the DROC (Dienst Regionaal Operationeel Centrum). The DROC receives all the calls of emergencies and has an overview of the entire Unit and its available emergency units. The first flowchart (Figure 5.1) shows what happens when an incident is received by the Unit. The second flowchart (Figure 5.2) shows what happens when an incident is finished.

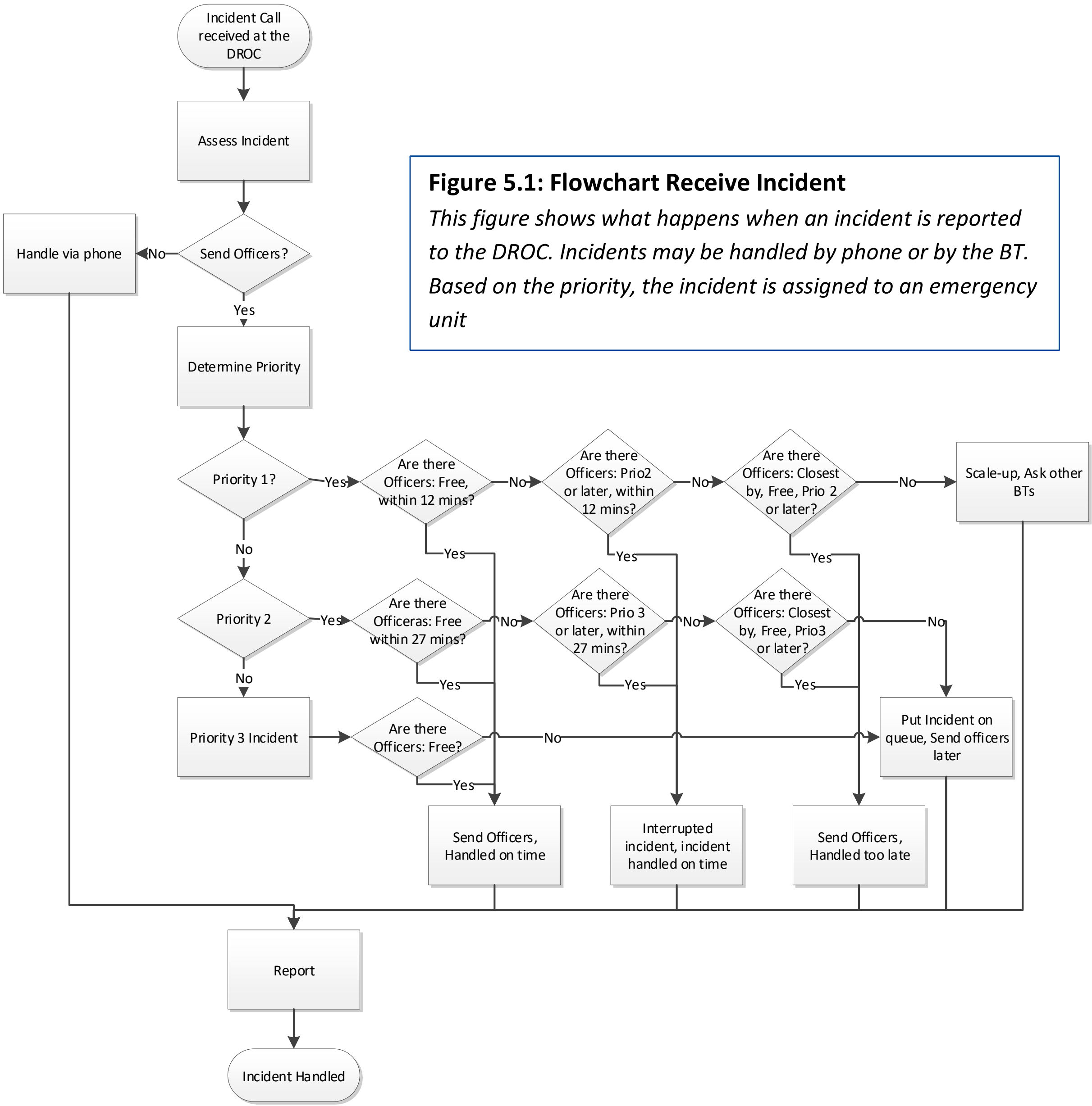
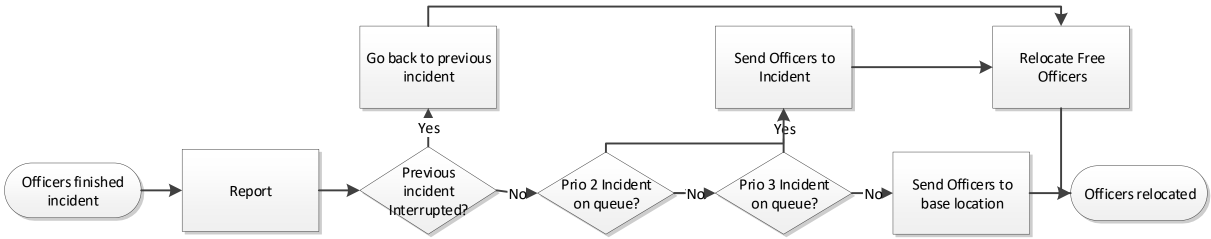


Figure 5.1: Flowchart Receive Incident

This figure shows what happens when an incident is reported to the DROC. Incidents may be handled by phone or by the BT. Based on the priority, the incident is assigned to an emergency unit

Figure 5.2: Flowchart Incident Finished

This figure shows what happens when an incident is finished by an emergency Unit. The result of the incident is reported and the vehicles returns to their interrupted incident, gets assigned one form the queue or returns to their base location.



5.1.3 Description

The two flowcharts are described below. First the flowchart 1, concerning the creation of a new incident, is described and after that the flowchart 2, when an incident is finished.

Flowchart 1 (Figure 5.1), an incident arrives at the DROC a quick assessment is made of the priority type. In some cases, it may be that the BTs don't have to respond, the call may then be handled by the phone. This, e.g., may be the case for incidents where only an ambulance is required or when there is a false alarm. When a BT has to respond the incidents are assessed as being priority one, two or three.

In the case of a priority one incident, the highest priority, an emergency unit should be dispatched as soon as possible. Priority one incidents should be serviced within fifteen minutes. On average, an incident call takes three minutes, this leaves twelve minutes for the response teams to get to the location in-time. When an emergency unit is readily available, they are dispatched to the incident. If no unit is within the vicinity, the DROC looks for an emergency unit that is currently occupied with less urgent matters. If no emergency units are able to reach the incident in-time, the unit that is closest by, not handling a priority one incident, is dispatched to the incident. The unit may not reach the incident in-time. However, officers will arrive to handle the incident. If even this is not possible, which is highly unlikely, help may be called in from other BTs.

Not all incidents are priority one incidents, there is also the option that there is a priority two or three incident. In the case of a priority two incident, the DROC will look for officers readily available within 27 minutes of the incident location (priority two incidents should be serviced within 30 minutes). If no such emergency units are available, the DROC will look for emergency units that are within the 27-minute radius and busy with a priority three incident. If these are also not available, emergency units that are not within 27 minutes and not busy with priority one or two incidents are called in to service the incident. If even now no units are available, the incident is put on a priority two queue. Priority three incidents are also serviced, though these do not have a time limit. The incident is serviced by the officers that are nearest and are free/not occupied by another incident.

When officers are servicing priority two and three incidents, they may be interrupted because they have to attend a higher priority incident. The priority two or three incidents are then paused, ready to be picked up by the officers when they finish the higher priority.

Flowchart 2 (Figure 5.2), an incident is finished, emergency units may continue to service the incident they left for a higher priority incident, service an incident waiting in the queue, priority two or priority three, or they may return to their base location.

5.1.3.1 Level of detail

The simulation model zooms in on the individual level of emergency units, this number is equal for each BT to the number of assigned vehicles. Whether these vehicles contain one, two or more officers is not taken into account. The arrival rate of incidents will vary for each hour of the week, e.g. the arrival rate will be highest around Saturday in the evening and lowest Monday to Friday around six in the morning. There will be no variation in arrival rate between weeks, since there was no clear indication of seasonal variation across the BTs.

5.1.3.2 Scope

The simulation scope consists of servicing incidents of priority one, two and three. Incidents handled by phone are not part of the model, because they are not handled by the BTs. All demand for the emergency vehicles stems from incidents, this assumption is discussed in the next section. All demand is handled by an emergency vehicle within the Unit, not by vehicles from neighbouring Units, other Units are not in scope.

5.1.3.3 Assumptions

Several assumptions are made for the simulation model of striped vehicles. Here these assumptions are mentioned and explained.

All demand from Incidents

The model aggregates all demand for the BT's from reported incidents. This is because it is their primary use and because most of the demand stems from incidents. This is also the primary data source available and the on-time response time is one of the most important performance indicators for the BT's.

One vehicle per Incident

We assume only one vehicle has to be present for each incident. In real cases it may be that multiple vehicles are required to service an incident. Unfortunately, there is no data available on the number of vehicles per incident. In addition, once an incident is being handled, excess vehicles can be assigned to new incidents.

Vehicle availability

All vehicles are available 24/7 and there are enough officers to available to drive them. There is no loss of vehicle availability or coverage due to shift changes of officers. The impact of these assumptions might not be very large depending on the simultaneous workload and the vehicle allocation. If the workload is low, not all vehicles will be in use and officers can change shifts without having any impact on the actual coverage. When vehicles are allocated to a police station, shift changes do not require the repositioning of a vehicle.

Interrupted incidents

A higher priority will take precedence over a lower priority. Because of this it is assumed that, when a higher priority occurs, another incident that is currently being serviced may be interrupted. In some cases, this will be true, in other cases this may not be true. Also, an interrupted incident is always picked up by the same officers that first handled the incident. This may not always be true in reality.

5.1.4 Experiments

The duration of a simulation cycle will span a year, which is about the same period of time after which capacity allocation may be reviewed. The experiments conducted with this simulation will focus on validating the distribution model described in Section 4.2. To check the relative performance four experiments will be conducted:

1. Validation (same conditions)
2. Added demand variation per week hour
3. Randomized locations
4. BT headquarters

The first experiment is used to validate the simulation model and the distribution model. To compare the results for both models, the conditions should be roughly the same. In the distribution model, only an average demand is considered, whereas for the simulation model, it is possible to add differences in demand per hour of the week. This **first experiment** assumes that all demand has an equal spread for each hour. The **second experiment** shows the results when demand is not equally spread throughout the week. Performance may be better during quit hours, and worse at peak hours. This model shows a more realistic demand pattern. The **third experiment** provides a base reference point in case all vehicles are allocated at random. The **fourth experiment** shows the performance when all vehicles are placed at the main locations of the BTs. This may be an interesting experiment because part of the jobs the officers do, happens at the offices of the BTs. BTs may decide whether it is worth it to sacrifice some of the coverage in order to increase office efficiency.

5.1.5 Results and Validation

The results of the simulation model should provide a validation of the distribution model. The simulation experiments provide insight into the response of the BTs when a distribution is applied. Table 5.1 shows the aggregated results of the four experiments conducted.

Experiment	Name	P(Wait)	P(Interrupted)	# Incidents	Wait Count
1	Validation	0.0000%	0.0000%	177220	0
2	Added Demand Variation	0.0000%	0.0000%	177431	0
3	Randomized Locations	47.6957%	6.3351%	173932	82958
4	BT Headquarters	19.5664%	8.8994%	177427	34716

Table 5.1: Simulation results Emergency Vehicles, An aggregated overview of simulation results. Four experiments have been conducted. The key performance indicator is the probability of having to wait. The probability of interrupted is introduced by the workflow (Figure 5.1 and 5.2), showing the percentage of incidents interrupted because of a higher priority incident.

5.1.5.1 Validation

The results from the simulation model show a similar performance result compared to the distribution model from Chapter 4. The probability of having to wait is 0%, meaning that the probability of being in-time is 100%, nearly the same as the distribution model, which showed one missed incident in a year. The number of incidents per year is also similar to the expected number of incidents, 176,998 for the distribution model and 177,220 for the simulation model.

5.1.5.2 Result Discussion

Experiment two, Added Demand Variation, adds the demand variation per hour. This experiment shows no difference in performance compared to experiment 1. The probability of having to wait is the same as in the Validation experiment, as is the Disruption probability and the number of incidents.

The third experiment, Randomized Locations, shows a clear shift in performance. At least 47% of the incidents are not serviced in-time 6% being interrupted. This is due to large inequalities in the vehicle distribution. Some teams get very few vehicles, causing the incidents to wait in the queue. Also, the vehicles are not placed at logical locations, causing the coverage to be suboptimal, increasing the probability of having incidents that cannot be reached in-time.

The fourth experiment, BT Headquarters, shows a near 20% waiting and 9% interrupted probability. This is close to the goals of the Police, getting at incidents in-time 80% of the time. Based on the simulation results, the Unit should be able to reach the goal while allocating all vehicles at the ten main locations of the BTs.

5.2 Simulation of Civilian Vehicles

The simulation of the civilian vehicles will focus on the effects of distributing the vehicles amongst the teams or locations and whether to incorporate demand for standby-services within the team or location pools or to have separate assignment of standby vehicles to standby demand. An analytical model has already been provided in Section 4.2. The two models should validate each other in order to support the results of both models. The next section will elaborate the results.

5.2.1 Goals

The goal of the civilian vehicles is to support all personnel of the Unit with their travel needs requiring a standard civilian vehicle. The Unit is looking for ways to improve the distribution of vehicles. Two options have been elaborated upon; assigning vehicles to teams or locations, sharing the vehicles amongst the teams at a location, and assigning vehicles to standby-services separately or servicing this demand from the same pool as general demand. Using the simulation model, the following performance indicators will be measured:

- Part of general demand that has to wait
- Part of standby demand that has to wait
- Total general demand
- Total standby demand
- Average waiting time of general demand
- Average waiting time of standby demand

5.2.2 Flowchart

For the civilian vehicle the process of vehicle assignment to civilian vehicle demand is separated into three flowcharts. The flowcharts show what happens when a task is created or when a vehicle returns.

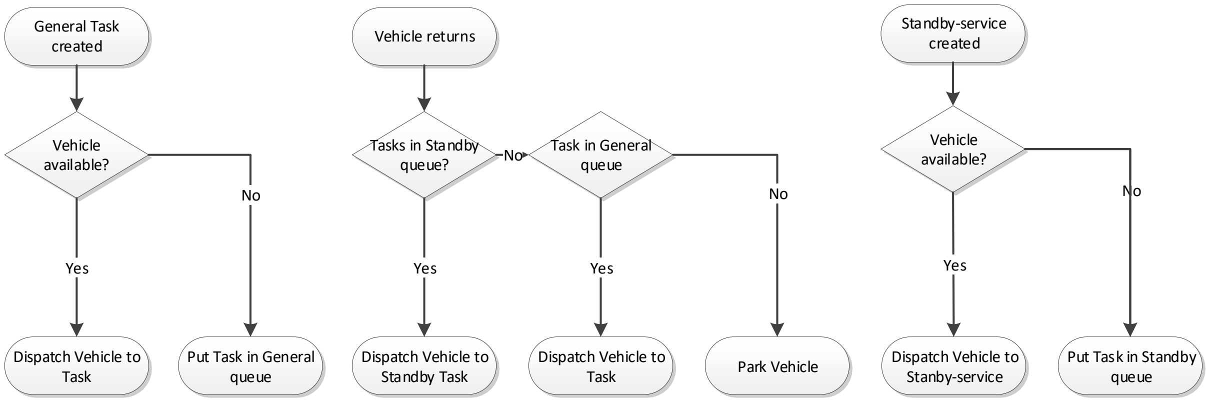


Figure 5.3: Flowcharts Civilian Vehicle
This figure shows what happens when with the civilian vehicles in three sub-processes. The first considers General tasks, the second shows what happens when a vehicle returns and the third shows what happens when Standby-services are required.

5.2.3 Description

The flowcharts show what happens when a task is created at a team. A description can be read below. The first flowchart shows what happens when a regular task is created. The employee will get to the pool assigned to the team and if a vehicle is available the employee is able to exercise the task. If there is no vehicle available, the employee has to wait until a vehicle becomes available.

The second flowchart depicts the event that a vehicle returns, when a task has been finished. First a check is done whether there are co-workers waiting to use a vehicle for a standby-service. These tasks are prioritised over general tasks. If no standby tasks are waiting at the pooled location, a general task in waiting can use the vehicle. If there are no tasks waiting for this vehicle it can be parked.

The third flowchart is similar to the first flowchart, however the tasks concerned here are standby-service tasks. When a vehicle is ready to perform a standby task, the standby task can be serviced. In the case of scenario 2 and 4, the standby vehicles are added to the general Team or Location pool. For these scenarios, when no vehicle is readily available, these tasks are added to a waiting queue. In the case of scenario 1 and 3, vehicles are specifically assigned to standby-services and there will never be a waiting time for standby-services.

5.2.3.1 Level of detail

The simulation model zooms in to the team level. Each team is comprised of a set of employees equal to the FTEs of that team. Depending on the scenario of the simulation, the team has vehicles assigned to the team or assigned to the location where the team is located.

5.2.3.2 Scope

The model will contain all the teams for which an indication of civilian vehicle usage was given. Only demand from within the Unit is considered, this also contains demand that may be executed outside the Unit area. An example of this is when employees of the AVIM team need to go to the immigration centre in Ter Apel (Unit Noord-Nederland).

5.2.3.3 Assumptions
Several assumptions have been made to simplify the model and to accommodate the reorganization of teams and locations within the Unit. The assumptions have been

Demand
There have been made several assumptions for the demand because there is very little information available on the use of the vehicles and because the teams are reorganised (causing the little data available to be even less accurate). Not every team and location require the use of civilian vehicles. All demand for civilian vehicles has been estimated based on mileages and expected use. The frequency and duration are assumed to follow an exponential distribution. The numerical data available showed an exponential distribution which is why this distribution is assumed here. Demand is expected to be larger during the start of the day because this will be the time employees will get their vehicles for the tasks they want to complete during the day.

Waiting
It is assumed that all demand will be fulfilled, that there is no loss of demand due to waiting. Though some demand will be lost when there is no vehicle available, it is expected that when appointments cannot be fulfilled when there is no vehicle available, the appointments will be made when a vehicle will be available. This assumption makes sure the same workload applies to the four scenarios.

No scheduling
All demand is expected to come in when it comes in. There is no scheduling and reservation of capacity. Some demand can be scheduled very well. However, it is expected that when vehicles can be scheduled, some employees may schedule, but not use the vehicles. For this reason, a non-plannable model has been chosen.

Separate Regular and Standby demand
Regular and standby demand are not expected to mix with. This is done to highlight the effects on both types separately. In the day to day business this is much harder to analyse since demand during the day is likely to mix for most of the standby-services since the tasks executed within the standby-services are police tasks. During the day the demand for standby-services should be fulfilled by the employees doing their daily business. What is still common though, is that for nearly all standby-services, the standby duty is executed for 24 hours of a day, which is interpreted for some standby-services to require a vehicle for those 24 hours. Regardless of the real demand.

5.2.4 Experiments
The experiments to be conducted consist of four scenarios.

- Validation: Simulation model without workday shifts
- Scenario 1: Distribution on team level, with separate standby-cars
- Scenario 2: Distribution on team level, incorporating standby demand to teams
- Scenario 3: Distribution on location level, with separate standby-cars
- Scenario 4: Distribution on location level, incorporating standby demand to locations

The first experiment acts as a baseline to determine whether the simulation will lead to the same results as the distribution in similar conditions. In this case the condition is that all demand take place continuously. There are no dayshifts, people work around the clock.

5.2.5 Results & Validation

The results of the simulation model should provide a validation to the distribution model introduced in Chapter 4 and show how the teams may respond to the proposed scenarios. The outcome of the distribution model is the input for the simulation model. Besides validating the distribution model, the simulation results will also be part of the validating the simulation model, as being representative for the process as depicted in the flowcharts (Figure 5.3). The following results have been gathered to validate both models.

Table 5.2: Civilian Simulation results: Waiting Probability for each experiment found using the analysis from Chapter 4 (second column) and the Simulation from Chapter 5 (third column)

Experiment	P(Wait) Analysis	P(Wait) Simulation
Validation	8.86%	9.02%
Scenario 1	8.86%	2.50%
Scenario 2	5.14%	1.80%
Scenario 3	0.30%	0.05%
Scenario 4	0.05%	0.03%

5.2.5.1 Validation

The simulation and distribution results are fairly similar in case of the validation experiment. There is a slight difference that occurs, when looking at the individual waiting probabilities for each queue, when the buffer is bigger in the simulation equivalent. For queues having the same buffer size, the results are identical, identical for whole percentages. The main simulation model and distribution analysis model are comparable in performance.

5.2.5.2 Result Discussion

Viewing the results of the four Scenarios, it seems that combining resources will generally lead to a lower chance of having to wait. The results of the experiments, scenario 1, 2, 3 and 4, show results that are lower than analysed queueing models showed. This is due to the appliance of working hours to the simulation model. The effect of having to wait decreases when applying the working days because the current load for each queue is reduced each day. After a dayshift has ended, rides can be finished, but new rides won't be started until the next shift. The next shift starts after 16 hours during the week, or after 64 hours in the weekend between Friday and Monday. This will cause most queues to be resolved, resulting in minimal waiting times at the start of each day. During the day waiting times may add up again. The average waiting time in seconds is 298.2, 164.5, 0.7 and 0.5 respectively for scenarios 1, 2, 3 and 4. This means that the scenario having the lowest chance of having to wait and the lowest expected waiting time is scenario 4.

6. Conclusion and Advice

This chapter provides the answer to the main research question and advice on things to be considered and further research. The main research question:

> *How should the Unit of Noord-Holland redistribute its vehicles across Noord-Holland, to maximize its mobility?*

Will be answered first in the conclusion of this research. Following this conclusion some advice will be discussed. The advice should be taken into consideration combined with the research results in this paper.

6.1 Conclusion

To maximize the mobility of the employees, the Unit should distribute its Emergency vehicles such that the coverage is optimal. The Unit should create a pool of Civilian vehicles at each office and service both regular demand and standby-service demand from these pools.

The emergency vehicles should be placed as shown in Figure 6.1. This distribution will lead to zero incidents not being serviced in-time and without disrupting any incidents. The number of vehicles assigned to the BTs is shown in Table 6.1.

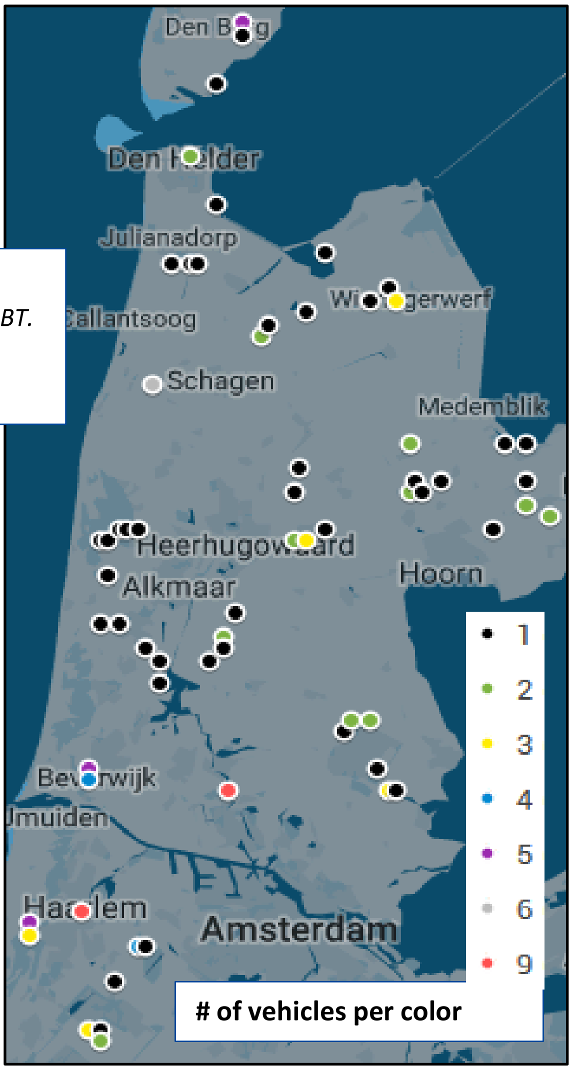


Figure 6.1: Emergency Vehicle Locations
shows the locations of vehicles assigned, color coded for each BT. The figure only shows the locations where a vehicle is placed. Multiple vehicles may be placed at one location.

Base Team	# of Vehicles
Den Helder	19
Heerhugowaard	18
Alkmaar	16
Hoorn	15
Haarlem	9
Haarlemmermeer	12
Kennemerkust	8
IJmond	9
Zaanstad	9
Purmerend	10

Table 6.1: Vehicle allocations per Base Team: This table shows the number of vehicles assigned to each Base Team.

The civilian vehicles should be placed as shown in Table 6.2. This will result in an average possibility of having to wait of 0.027% and an expected waiting time of 0.5 seconds for general rides and 0 seconds for standby-services.

Location	FTE	# of Vehicles	P(Wait)	E(Wait) (seconds)
Haarlem, Koudenhorn	468	50	0.10%	1.80
Alkmaar, James Wattstraat	235	29	0.00%	0.00
Hoofddorp, Hoofdweg	165	9	0.00%	0.00
Beverwijk, Laan der Nederlanden	185	7	0.00%	0.00
IJmuiden, Tiberiusplein	131	9	0.00%	0.00
Zandvoort, Hogeweg	110	7	0.00%	0.00
Heemskerk, Maerten van Heemskerkstr	60	18	0.00%	0.00
Alkmaar, Mallegatsplein	300	37	0.00%	0.00
Den Helder, Bastiondreef	165	9	0.00%	0.00
Schagen, Koperwiek	2	2	0.00%	0.00
Heerhugowaard, Zuidtangent	150	7	0.00%	0.00
Hoorn, Blokmergouw	192	7	0.00%	0.00
Grootebroek, Industrieweg	1	1	0.00%	0.00
Zaandijk, Guishof	368	30	0.00%	0.00
Purmerend, Waterlandlaan	155	5	0.00%	0.00
Zaandam, Prins Bernhardlaan	39	4	0.00%	0.00
Alkmaar, Hertog Aalbrechtweg	162	13	0.00%	0.00
Haarlem, Zijlweg	29	4	0.00%	0.00
Alkmaar, Europaweg	45	17	0.00%	0.00
Haarlem, Mariettahof	45	17	0.00%	0.00
Alkmaar, Amperestraat	46	11	0.12%	0.13
Overveen, Dompvloedslaan	39	7	0.00%	0.00
Alkmaar, Krusemand van Eltenweg	114	11	0.00%	0.00

Table 6.2: Pool Locations: This table shows the number of vehicles at each office requiring vehicles. The first column shows the city and street name. The second column shows the number of FTEs being serviced by the number of vehicles assigned, shown in column 3. Columns 4 and 5 show the performance results per location as P(Wait), probability of having to wait, and E(Wait) (seconds), the expected waiting time in seconds.

6.2 Advice

This part will discuss the conclusion and results provided in this paper until here. Advice will be provided based on observations during the research of this paper. The primary advice is to distribute the vehicles according to the distributions while taking some key notes into consideration. These considerations are elaborated upon in the next two sections

6.2.1 Emergency vehicles

With regard to the emergency vehicles, only incidents and response times are considered. The bottleneck on servicing incidents in-time is not the number of vehicles available. Other decisions might influence the in-time handling of incidents more than the available vehicles. To increase the in-time response times for incidents, the Unit might have to start a research into what other factors there are that influence the response-times and to make decisions on these factors. The distribution model shows a very promising emergency vehicle allocation. The Unit may want to experiment with this distribution model as a tool for the DROC to improve the incident coverage of available emergency units.

6.2.2 Civilian Vehicles

With regard to the civilian vehicles, it is beneficial for all teams involved to share vehicles amongst each other. This will create the lowest probability of missing out on a vehicle while vehicles are available at the locations. Keep track of the actual vehicle usage of teams. The distribution of vehicles to the office locations is based on estimations for each team. These numbers should be revisited at least once a year and vehicle shifts will probably occur due to new knowledge about the actual use by the teams. It is also advised to satisfy the standby-service demand from the same vehicle pool, since there are enough vehicles present to service the demand of both regular and standby-services. Make sure to create a contingency plan, in the unlikely event that a vehicle is required when no vehicle is available. Look for a method to share vehicles across the Unit at the offices, several existing options are noted in Chapter 2. Be aware of making 'vehicle reservations' as these might prompt employees to make a vehicle reservation just in case they might need a vehicle. Vehicles may become administratively unavailable while they are standing still.

6.3 Further Research

During the research question come up that do not fall within the boundaries of this research. These questions did not get an answer here, but they may be answered in another project. This paragraph focusses on possible areas of further research based on the research done in this paper.

Already in Section 3.2.1, several (civilian) vehicle sharing systems are mentioned. This research has shown that vehicle sharing is very beneficial to the Unit. The way a vehicle sharing system will be implemented is not clear yet. Existing concerns are that vehicles are not available when needed, this may prompt the use of a reservation system. The problem with a reservation system is that users might create a reservation, even if there is only a slim chance of needing one. This may block other users from actually using a car. Finding the best fit for the Unit of Noord Holland will be well worth the search. Another option to consider is the use of vehicle distribution that assigns part of the vehicles to teams and part of the vehicles to a vehicle pool. This results for this option will likely fall in between the results found for the four scenarios. How to assign vehicles to teams and how to assign vehicles to a pool will have to be decided.

For emergency vehicles, continued research into the tasks and the required capacities for BTs will provide further insight into the performance of the BTs and how different aspects will impact the incident performance measures. More detail may be added in the form of specific emergency vehicle types being better equipped to handle specific incident situation, for example a small bus may be better suited to transport officers to incidents at large groups of people, and by incorporating the possibility that more than one vehicle may be required to service an incident, for example when trying to capture someone who is on the run. The performance of vehicle allocations can be analysed further, comparing the allocations done by the DROC to the allocations done by an automated algorithm. It may prove beneficial to provide the DROC with a vehicle allocation advice, given the number of available emergency units and the historical data on incidents.

For both vehicle types, extended research into what happens in extreme situations is an interesting. Though extreme situations are not likely to happen, they do happen, such the plane crashes in 1992

(Bijlmer) and 2009 (Turkish-Airlines). Knowing how to respond in these kinds of situation is highly valuable to the Police force.

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Appendices

Appendix A - Interview

Below the interview template can be viewed. These were the questions asked to each team to get an understanding in the vehicle usage.

Intaker voertuigen : 'Interviewers'

Datum : 'Date'

Onderwerp : 'Subject – Reason of interview and Team'

Geïnterviewde : 'Interviewee'

Op welke locatie is de afdeling werkzaam?
'From which locations does the team work?'
Wat is de huidige Fte bezetting en hoe verhoudt zich dat ten opzichte van het Formatieplan?
'What is the current FTE occupation and how does it hold against the formation plan?'
Samenvatting van het voertuigenbestand
'Summary of the team's vehicles'
Omschrijving van werkprocessen van afdeling/ basisteam
'Description of the processes of the team'
Is uw team/afdeling belast met afwijkende diensten bv. piketdiensten? Zo ja wat voor piketdiensten en (inzet)frequenties
'Is your team tasked with extraordinary services such as standby-services? If so, what kinds of standby-services and what is the intensity of these services?'
Maakt uw team/afdeling gebruik van specialistische voertuigen? Zo ja wat voor soort voertuigen en waarvoor?
'Does your team use specialised vehicles? If so, what kind of vehicles and to what end?'
Wat is de vervoersbehoefte gelet op de aard van de werkzaamheden van uw team/afdeling?
'What are the transportation needs, considering the nature of the activities of your team'
Voldoet het huidige aantal voertuigen aan de vervoersbehoefte van het team/afdeling (beargumenteer)?

'Does the current number of vehicles satisfy the transportation needs of your team?'
Ziet u mogelijkheden om de voertuigen van uw team/afdeling efficiënter en of effectiever in te zetten? Zo ja op welke wijze?
'Do you see opportunities in order to improve the application of the vehicles for your team? If so, how?'
Onder welke voorwaarden zou u akkoord gaan wat betreft uw team/afdeling met gebruik van poolvoertuigen? Vb. welke functies?
'Under which circumstances would you agree to the use of pooled vehicles? E.g. what functions?'
Wij maken van dit interview een gespreksverslag. Wij sturen dit verslag binnen een week naar u toe. Naar welk e-mail adres kan dit verslag gestuurd worden?
'A report will be made of this interview. We will send the report to you within a week. To which address(es) shall we send the report?'

Aanvullende aantekeningen:

'Additional notes'

Appendix B - Queueing Results

In this appendix the detailed queueing results can be found from the queueing analysis in Section 4.3. The results show the vehicle allocations to each queue, team or location depending on the scenario, the number of FTEs, the probability of missing out and the average expected waiting time.

Overview

Scenario					Time in hours
1	P(Missing-out)WeightedAverage	0.089	8.86%	E(Waiting Time)	0.219
	P(Missing-out)Max	0.233	23.33%	E(Wait)Max	1.379
	P(Missing-out)Min	0.000	0.00%	E(Wait)Min	0.000
	P(Missing-out)Bandwidth	0.233	23.33%	E(Wait)Bandwidth	1.379
2	P(Missing-out)WeightedAverage	0.051	5.14%	E(Waiting Time)	0.063
	P(Missing-out)Max	0.215	21.48%	E(Wait)Max	0.547
	P(Missing-out)Min	0.000	0.00%	E(Wait)Min	0.000
	P(Missing-out)Bandwidth	0.215	21.48%	E(Wait)Bandwidth	0.547
3	P(Missing-out)WeightedAverage	0.003	0.30%	E(Waiting Time)	0.002
	P(Missing-out)Max	0.011	1.10%	E(Wait)Max	0.017
	P(Missing-out)Min	0.000	0.00%	E(Wait)Min	0.000
	P(Missing-out)Bandwidth	0.011	1.10%	E(Wait)Bandwidth	0.017
4	P(Missing-out)WeightedAverage	0.000	0.05%	E(Waiting Time)	0.000
	P(Missing-out)Max	0.001	0.12%	E(Wait)Max	0.001
	P(Missing-out)Min	0.000	0.00%	E(Wait)Min	0.000
	P(Missing-out)Bandwidth	0.001	0.12%	E(Wait)Bandwidth	0.001

Scenario 1

Queue	Team	Location	FTE	Vehicles	P(Wait)	E(WaitTime)
1	Politieprofessie	Haarlem, Koudenhorn	14	1	0.233	0.913
2	Control	Haarlem, Koudenhorn	9	1	0.233	0.913
3	BO	Haarlem, Koudenhorn	27	1	0.233	0.913
4	VIK	Haarlem, Koudenhorn	21	7	0.061	0.100
5	Communicatie	Haarlem, Koudenhorn	15	2	0.048	0.086
6	Haarlem	Haarlem, Koudenhorn	215	4	0.052	0.039
7	Haarlemmermeer	Hoofddorp, Hoofdweg	165	5	0.060	0.040
8	IJmond	Beverwijk, Laan der Nederlanden	185	4	0.052	0.039
9	Kennemerkust	Zandvoort, Hogeweg	110	4	0.052	0.039
10	DR_KEN	Haarlem, Koudenhorn	70	17	0.056	0.045
11	Flex_KEN	Haarlem, Koudenhorn	20	3	0.068	0.129
12	Alkmaar	Alkmaar, Mallegatsplein	200	6	0.062	0.037
13	Den Helder	Den Helder, Bastiondreef	165	5	0.060	0.040
14	Heerhugowaard	Heerhugowaard, Zuidtangent	150	4	0.052	0.039
15	Hoorn	Hoorn, Blokmergouw	190	4	0.052	0.039
16	DR_NHN	Alkmaar, Mallegatsplein	70	20	0.066	0.050
17	Flex_NHN	Alkmaar, Mallegatsplein	20	3	0.068	0.129
18	Zaanstad	Zaandijk, Guishof	200	4	0.052	0.039
19	Purmerend	Purmerend, Waterlandlaan	155	2	0.167	0.250
20	DR_ZAW	Zaandijk, Guishof	60	11	0.055	0.056
21	Flex_ZAW	Zaandijk, Guishof	20	2	0.167	0.375
22	ROC	Zaandam, Prins Bernhardlaan	30	1	0.222	1.143
23	ROC	Alkmaar, Hertog Aalbrechtweg	30	1	0.222	1.143
24	ROC	Haarlem, Zijlweg	20	1	0.222	1.143
25	Algemeen	Alkmaar, James Wattstraat	55	16	0.072	0.050
26	Algemeen	Haarlem, Koudenhorn	55	14	0.049	0.034
27	Algemeen	Zaandijk, Guishof	55	9	0.057	0.053
28	Milieu	Heemskerk, Maerten van Heemskerkstraat	20	4	0.124	0.223
29	Milieu	Hoorn, Blokmergouw	2	1	0.173	1.007
30	Milieu	Schagen, Koperwiek	2	1	0.173	1.007
31	FinEc	Heemskerk, Maerten van Heemskerkstraat	12	2	0.081	0.208
32	Zeden&KP	Heemskerk, Maerten van Heemskerkstraat	28	9	0.079	0.078
33	Zeden&KP	Alkmaar, Mallegatsplein	10	5	0.086	0.142
34	Zeden&KP	Haarlem, Koudenhorn	10	4	0.124	0.214
35	Zeden&KP	Zaandijk, Guishof	5	3	0.066	0.087
36	H&T	Alkmaar, Europaweg	15	5	0.071	0.156
37	H&T	Haarlem, Mariettahof	15	5	0.071	0.156
38	IO	Haarlem, Mariettahof	15	5	0.069	0.151
39	IO	Alkmaar, Europaweg	15	5	0.069	0.151
40	MC&M	Alkmaar, Europaweg	15	5	0.067	0.145

Scenario 1 extended

Queue	Team	Location	FTE	Vehicles	P(Wait)	E(WaitTime)
41	MC&M	Haarlem, Mariettahof	15	5	0.067	0.145
42	FO	Alkmaar, James Wattstraat	29	1	0.222	1.143
43	FO	Alkmaar, Amperestraat	10	1	0.222	1.143
44	FO	IJmuiden, Tiberiusplein	33	2	0.167	0.500
45	FO	Zaandijk, Guishof	23	1	0.222	1.143
46	FinO	Alkmaar, Amperestraat	3	1	0.220	1.143
47	FinO	Overveen, Dompvloedslaan	5	1	0.222	1.139
48	FinO	Zaandijk, Guishof	3	1	0.220	1.143
49	Digi	Alkmaar, Amperestraat	5	1	0.222	1.139
50	Digi	IJmuiden, Tiberiusplein	7	1	0.222	1.142
51	Digi	Zaandijk, Guishof	2	1	0.214	1.379
52	Ondersteuningsdesk	Overveen, Dompvloedslaan	10	3	0.068	0.128
53	Leiding_RI	Alkmaar, James Wattstraat	1	1	0.000	0.000
54	RIK	Alkmaar, James Wattstraat	26	2	0.167	0.500
55	RTIC	Alkmaar, Hertog Aalbrechtweg	9	1	0.222	1.143
56	RTIC	Zaandam, Prins Bernhardlaan	9	1	0.222	1.143
57	RTIC	Haarlem, Zijlweg	9	1	0.222	1.143
58	IRC	Haarlem, Koudenhorn	4	3	0.036	0.013
59	Leiding_IK	Haarlem, Koudenhorn	1	1	0.000	0.000
60	DIK	Alkmaar, James Wattstraat	42	2	0.081	0.208
61	IK DROS	Alkmaar, Hertog Aalbrechtweg	6	1	0.222	1.141
62	IK RR	Overveen, Dompvloedslaan	24	1	0.222	1.143
63	BICC	Alkmaar, James Wattstraat	1	1	0.000	0.000
64	KB&B	Alkmaar, James Wattstraat	5	1	0.222	1.139
65	A&O	Alkmaar, James Wattstraat	52	2	0.081	0.208
66	RSC	Alkmaar, Hertog Aalbrechtweg	76	3	0.068	0.257
67	Leiding_Arrest.	Alkmaar, Krusemand van Eltenweg	1	1	0.000	0.000
68	Z&T&P	Alkmaar, Krusemand van Eltenweg	113	5	0.103	0.270
69	Leiding	Grootebroek, Industrieweg	1	1	0.000	0.000
70	KCT	Alkmaar, James Wattstraat	22	3	0.068	0.129
71	Leiding	Alkmaar, Hertog Aalbrechtweg	1	1	0.000	0.000
72	ME	Alkmaar, Hertog Aalbrechtweg	7	2	0.148	0.423
73	OG	Haarlem, Koudenhorn	7	2	0.148	0.423
74	Leiding_Infra	IJmuiden, Tiberiusplein	1	1	0.000	0.000
75	VH	IJmuiden, Tiberiusplein	80	1	0.222	1.143
76	VA	Alkmaar, Amperestraat	8	3	0.068	0.127
77	VO	IJmuiden, Tiberiusplein	10	1	0.222	1.143
78	NO	Alkmaar, Amperestraat	20	4	0.124	0.223
79	TT	Alkmaar, James Wattstraat	2	1	0.163	0.600
80	P&CM	Alkmaar, Hertog Aalbrechtweg	33	3	0.068	0.257

Scenario 2

Queue	Team	Location	FTE	Vehicles	P(Wait)	E(WaitTime)
1	Politieprofessie	Haarlem, Koudenhorn	14	2	0.025	0.043
2	Control	Haarlem, Koudenhorn	9	2	0.024	0.041
3	BO	Haarlem, Koudenhorn	27	2	0.024	0.041
4	VIK	Haarlem, Koudenhorn	21	7	0.061	0.100
5	Communicatie	Haarlem, Koudenhorn	15	2	0.048	0.086
6	Haarlem	Haarlem, Koudenhorn	215	4	0.054	0.041
7	Haarlemmermeer	Hoofddorp, Hoofdweg	165	5	0.062	0.042
8	IJmond	Beverwijk, Laan der Nederlanden	185	4	0.054	0.041
9	Kennemerkust	Zandvoort, Hogeweg	110	4	0.053	0.041
10	DR_KEN	Haarlem, Koudenhorn	70	18	0.034	0.024
11	Flex_KEN	Haarlem, Koudenhorn	20	3	0.068	0.130
12	Alkmaar	Alkmaar, Mallegatsplein	200	6	0.064	0.039
13	Den Helder	Den Helder, Bastiondreef	165	5	0.062	0.042
14	Heerhugowaard	Heerhugowaard, Zuidtangent	150	4	0.054	0.041
15	Hoorn	Hoorn, Blokmergouw	190	4	0.054	0.041
16	DR_NHN	Alkmaar, Mallegatsplein	70	21	0.043	0.029
17	Flex_NHN	Alkmaar, Mallegatsplein	20	3	0.068	0.130
18	Zaanstad	Zaandijk, Guishof	200	4	0.054	0.041
19	Purmerend	Purmerend, Waterlandlaan	155	3	0.035	0.031
20	DR_ZAW	Zaandijk, Guishof	60	11	0.062	0.064
21	Flex_ZAW	Zaandijk, Guishof	20	3	0.033	0.042
22	ROC	Zaandam, Prins Bernhardlaan	30	2	0.022	0.050
23	ROC	Alkmaar, Hertog Aalbrechtweg	30	2	0.022	0.050
24	ROC	Haarlem, Zijlweg	20	2	0.022	0.050
25	Algemeen	Alkmaar, James Wattstraat	55	17	0.043	0.026
26	Algemeen	Haarlem, Koudenhorn	55	14	0.054	0.038
27	Algemeen	Zaandijk, Guishof	55	9	0.065	0.062
28	Milieu	Heemskerk, Maerten van Heemskerkstraat	20	5	0.040	0.050
29	Milieu	Hoorn, Blokmergouw	2	1	0.176	0.491
30	Milieu	Schagen, Koperwiek	2	1	0.176	0.491
31	FinEc	Heemskerk, Maerten van Heemskerkstraat	12	2	0.084	0.219
32	Zeden&KP	Heemskerk, Maerten van Heemskerkstraat	28	10	0.037	0.030
33	Zeden&KP	Alkmaar, Mallegatsplein	10	5	0.089	0.147
34	Zeden&KP	Haarlem, Koudenhorn	10	5	0.040	0.048
35	Zeden&KP	Zaandijk, Guishof	5	3	0.068	0.087
36	H&T	Alkmaar, Europaweg	15	5	0.072	0.157
37	H&T	Haarlem, Mariettahof	15	5	0.072	0.157
38	IO	Haarlem, Mariettahof	15	5	0.070	0.153
39	IO	Alkmaar, Europaweg	15	5	0.070	0.153
40	MC&M	Alkmaar, Europaweg	15	5	0.067	0.146

Scenario 2 extended

Queue	Team	Location	FTE	Vehicles	P(Wait)	E(WaitTime)
41	MC&M	Haarlem, Mariettahof	15	5	0.067	0.146
42	FO	Alkmaar, James Wattstraat	29	2	0.023	0.051
43	FO	Alkmaar, Amperestraat	10	2	0.023	0.051
44	FO	IJmuiden, Tiberiusplein	33	3	0.033	0.057
45	FO	Zaandijk, Guishof	23	2	0.023	0.051
46	FinO	Alkmaar, Amperestraat	3	2	0.023	0.032
47	FinO	Overveen, Dompvloedslaan	5	2	0.023	0.052
48	FinO	Zaandijk, Guishof	3	2	0.023	0.032
49	Digi	Alkmaar, Amperestraat	5	2	0.023	0.050
50	Digi	IJmuiden, Tiberiusplein	7	2	0.023	0.051
51	Digi	Zaandijk, Guishof	2	1	0.215	0.547
52	Ondersteuningsdesk	Overveen, Dompvloedslaan	10	3	0.068	0.129
53	Leiding_RI	Alkmaar, James Wattstraat	1	1	0.000	0.000
54	RIK	Alkmaar, James Wattstraat	26	3	0.033	0.057
55	RTIC	Alkmaar, Hertog Aalbrechtweg	9	2	0.023	0.052
56	RTIC	Zaandam, Prins Bernhardlaan	9	2	0.023	0.052
57	RTIC	Haarlem, Zijlweg	9	2	0.023	0.052
58	IRC	Haarlem, Koudenhorn	4	3	0.037	0.011
59	Leiding_IK	Haarlem, Koudenhorn	1	1	0.000	0.000
60	DIK	Alkmaar, James Wattstraat	42	2	0.088	0.228
61	IK DROS	Alkmaar, Hertog Aalbrechtweg	6	2	0.023	0.051
62	IK RR	Overveen, Dompvloedslaan	24	2	0.023	0.053
63	BICC	Alkmaar, James Wattstraat	1	1	0.000	0.000
64	KB&B	Alkmaar, James Wattstraat	5	2	0.022	0.050
65	A&O	Alkmaar, James Wattstraat	52	2	0.085	0.221
66	RSC	Alkmaar, Hertog Aalbrechtweg	76	3	0.068	0.257
67	Leiding_Arrest.	Alkmaar, Krusemand van Eltenweg	1	1	0.000	0.000
68	Z&T&P	Alkmaar, Krusemand van Eltenweg	113	6	0.035	0.068
69	Leiding	Grootebroek, Industrieweg	1	1	0.000	0.000
70	KCT	Alkmaar, James Wattstraat	22	3	0.068	0.129
71	Leiding	Alkmaar, Hertog Aalbrechtweg	1	1	0.000	0.000
72	ME	Alkmaar, Hertog Aalbrechtweg	7	3	0.029	0.050
73	OG	Haarlem, Koudenhorn	7	3	0.029	0.050
74	Leiding_Infra	IJmuiden, Tiberiusplein	1	1	0.000	0.000
75	VH	IJmuiden, Tiberiusplein	80	2	0.022	0.050
76	VA	Alkmaar, Amperestraat	8	3	0.068	0.127
77	VO	IJmuiden, Tiberiusplein	10	2	0.022	0.050
78	NO	Alkmaar, Amperestraat	20	5	0.039	0.048
79	TT	Alkmaar, James Wattstraat	2	1	0.163	0.349
80	P&CM	Alkmaar, Hertog Aalbrechtweg	33	3	0.068	0.257

Scenario 3

Queue	Location	FTE	Vehicles	P(Wait)	E(WaitTime)
1	Haarlem, Koudenhorn	468	47	0.002	0.000
2	Alkmaar, James Wattstraat	235	26	0.003	0.001
3	Hoofddorp, Hoofdweg	165	7	0.005	0.002
4	Beverwijk, Laan der Nederlanden	185	6	0.003	0.001
5	IJmuiden, Tiberiusplein	131	8	0.002	0.002
6	Zandvoort, Hogeweg	110	6	0.003	0.001
7	Heemskerk, Maerten van Heemskerkstraat	60	16	0.003	0.002
8	Alkmaar, Mallegatsplein	300	34	0.002	0.000
9	Den Helder, Bastiondreef	165	7	0.005	0.002
10	Schagen, Koperwiek	2	2	0.000	0.000
11	Heerhugowaard, Zuidtangent	150	6	0.003	0.001
12	Hoorn, Blokmergouw	192	6	0.005	0.002
13	Grootebroek, Industrieweg	1	1	0.000	0.000
14	Zaandijk, Guishof	368	27	0.002	0.001
15	Purmerend, Waterlandlaan	155	4	0.005	0.003
16	Zaandam, Prins Bernhardlaan	39	3	0.011	0.017
17	Alkmaar, Hertog Aalbrechtweg	162	11	0.003	0.002
18	Haarlem, Zijlweg	29	3	0.011	0.017
19	Alkmaar, Europaweg	45	15	0.002	0.002
20	Haarlem, Mariettahof	45	15	0.002	0.002
21	Alkmaar, Amperestraat	46	10	0.002	0.001
22	Overveen, Dompvloedslaan	39	6	0.003	0.002
23	Alkmaar, Krusemand van Eltenweg	114	9	0.004	0.005

Scenario 4

Queue	Location	FTE	Vehicles	P(Wait)	E(WaitTime)
1	Haarlem, Koudenhorn	468	50	0.000	0.000
2	Alkmaar, James Wattstraat	235	29	0.000	0.000
3	Hoofddorp, Hoofdweg	165	9	0.000	0.000
4	Beverwijk, Laan der Nederlanden	185	7	0.001	0.000
5	IJmuiden, Tiberiusplein	131	9	0.001	0.000
6	Zandvoort, Hogeweg	110	7	0.001	0.000
7	Heemskerk, Maerten van Heemskerkstraat	60	18	0.001	0.000
8	Alkmaar, Mallegatsplein	300	37	0.000	0.000
9	Den Helder, Bastiondreef	165	9	0.000	0.000
10	Schagen, Koperwiek	2	2	0.000	0.000
11	Heerhugowaard, Zuidtangent	150	7	0.001	0.000
12	Hoorn, Blokmergouw	192	7	0.001	0.000
13	Grootebroek, Industrieweg	1	1	0.000	0.000
14	Zaandijk, Guishof	368	30	0.000	0.000
15	Purmerend, Waterlandlaan	155	5	0.001	0.000
16	Zaandam, Prins Bernhardlaan	39	4	0.001	0.001
17	Alkmaar, Hertog Aalbrechtweg	162	13	0.000	0.000
18	Haarlem, Zijlweg	29	4	0.001	0.001
19	Alkmaar, Europaweg	45	17	0.000	0.000
20	Haarlem, Mariettahof	45	17	0.000	0.000
21	Alkmaar, Amperestraat	46	11	0.001	0.000
22	Overveen, Dompvloedslaan	39	7	0.001	0.000
23	Alkmaar, Krusemand van Eltenweg	114	11	0.000	0.000