2015•2016
SCHOOL FOR TRANSPORTATION SCIENCES
Master of Transportation Sciences

Master's thesis

Sustainable Investments in the Road Network Considering the Introduction of Automated Vehicles

Supervisor :
prof. dr. ir. Ansar-Ul-Haque YASAR

Co-supervisor :
Prof. dr. Tom BRIJS

Xavier Boonman

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

Universiteit Hasselt | Campus Hasselt | Martelarenlaan 42 | BE-3500 Hasselt
Universiteit Hasselt | Campus Diepenbeek | Agoralaan Gebouw D | BE-3590 Diepenbeek

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KNOWLEDGE IN ACTION

Preface

This thesis is submitted in partial fulfilment of the requirements for a Belgium Master's degree in Transportation Sciences specialisation Mobility Management at Hasselt University. This consists of two parts and it contains 30 European Credit Transfer System (ECTS) in total. It contains research done from September 2015 until June 2016. My supervisor and promotor is Ansar Yasar and my co-promotor is Tom Brijs, both professors at Hasselt University. This thesis has been made solely by the author and most of the text is based on secondary research. All of the sources can be seen in the references.

My bachelor thesis was about if drivers would influence their route under influence of commercial messages. Therefore, I was interested in how to inform drivers in the future as there is a trend to have more information systems on-board instead of off-board and in the future with automated vehicles. I contacted Gert Blom at 4 August 2015 with the question if he had any thesis questions regarding this subject. As Ansar Yasar has a broad knowledge about automated vehicles, I asked him to be my supervisor.

Writing this thesis has been a challenge because I did not know much about automated vehicles when I started. However, during the process, I became better in writing this thesis and I have learned a lot.

Several persons have contributed academically, practically and with support to this master thesis. Firstly, I thank my head supervisor Prof. dr. ir. Ansar Yasar and co-supervisor Prof. dr. Tom Brijs for their time, valuable input and support throughout the entire master period. Furthermore, I would like to thank Gert Blom from "Gemeente Helmond" and Kristof Rombaut from "Agentschap Wegen en Verkeer" for their big help throughout the entire process.

Besides, I to thank Peter Defreyne, Bart van den Berg, Laurens Schrijnen, Peter Hoernig and Yves Coox, for their constructive comments to the thesis.

I would like to thank my family in supporting me with my thesis. They always looked it at the bright side.

Last, I would like to thank my classmates and friends for being helpful and supportive during my time studying Transportation sciences at Hasselt University.

Xavier Boonman

1 June 2016

Acknowledgment

Title
Sustainable investments in the road network considering the introduction of automated vehicles

Author
Xavier Boonman
1130938
+31658988372
xboonman@hotmail.com

Course unit
Master thesis

Master in Transportation Sciences
School for Transportation Sciences
Hasselt University

Promotor
Prof. dr. ir. Ansar Yasar

Co-promotor
Prof. dr. Tom Brijs

Mentor
Gert Blom

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Summary

Currently, governments invest a lot of money in the road network. There is a trend that automated vehicles will play a big part in the transportation system of the future. Therefore, the main research question is: "How can the current investments in the road network be made sustainable for the introduction of automated vehicles?"

Automated vehicles are vehicles where at least some facets of a safety-critical control function occur without direct driver's influence. Vehicles that provide safety warnings to drivers and do not execute a control function are not considered as automated. There are five levels of automation from no automation to full automation. Currently, the technology is at level two and there are hard efforts to increase the level of automation rapidly. Car manufactures assume that cars will reach level of automation five within four years. However, some professors say it will take a lot longer to reach. Nevertheless, if it is reached, the advantages clearly outweigh the disadvantages.

The communication between cars and infrastructure probably will be a hybrid situation, with both WI-FI-P (ITS-G5) as well as 4G/5G cellular communication. Time-critical applications will merely depend on WI-FI-P, whereas less time-critical applications are distributed to a larger number of users via cellular network.

The first traffic signs that will disappear are the static information traffic signs without any justice value. After that, the most likely is that all traffic signs at highways will disappear. However, not all traffic signs be removed, since some signs are needed for bicyclists and pedestrians.

There is a need of digital and physical infrastructure. The road authority probably will invest less in the road network and more in the digital infrastructure. Furthermore, Telecom providers will play an important role in the digital infrastructure. The traffic centres will be in charge of the command and prohibition traffic signs.

The analysis part summarizes some case studies. The first case study is about how the police still need a kind of enforcement and traffic management on the scene. It is good that the police will invest in WI-FI-P equipment to communicate with automated vehicles.

The second case is the Flemish traffic sign database. It is a database set up by the Flemish government to have a good overview about where all traffic signs are. To keep the database up-to-date, it is good that there is a rapid response team. In the short term most of the traffic signs will stay, but they will disappear in the long term.

Road intersections probably will change a lot, as it is shown in the third case. There will be need for a small server at each intersection to receive the signals from the vehicles.

The fourth case is about the infrastructure asset management. Governments get information quicker and therefore, they can adapt their policy to maintain the road. It is important that governments are responsive for this change.

The last used case is about road works. The road workers will inform the traffic management centre about the starting and end of the work. The traffic centre will send this information to all vehicles how to conduct in this situation. The role of the traffic centre will slightly change due to the fact that the communications will be directly via 4G to the vehicles.

Lately, the member states of the European Union (EU) have agreed on the declaration of Amsterdam. This will increase a uniform policy in Europe, which is positive for the implementation of the automated vehicle.

The first step for policy making is to recognise what an automated vehicle is and what the benefits are. The second step is to do many tests in closed circuit and on the road. The third step is to make law about the implementation of automated vehicles. And the last step to make policy about how to implement automated vehicles.

To conclude this report and write about the investments which are necessary or not. According this investigation, it is important to invest in a central database where different stakeholders can tap in for different purposes. The different governments should invest in the connection to this database and the different applications they want to provide. It also is important to invest in in-car systems used by WI-FI-P and 5G standards. It is less useful to invest in roadside systems, except for systems to capture the communication.

Keywords: Policy, infrastructure, communication, automated vehicle, government, traffic signs.

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List of Abbreviations

Abbreviation	**Explanation**
4G/5G	Cellular mobile network
AIM	Automated intersection management
CEN	European Committee for Standardization
C-ITS	Connected Intelligent Transportation systems
CVAS	Cooperative Vehicle Actuator System
DARPA	Defence Advanced Research Projects Agency
DCP	Distributing Clearing Policy
DSRC	Dedicated Short Range Communication
ECTS	European Credit Transfer System
ETSI	European Telecommunications Standards Institute
EU	European Union
GPS	Global positioning system
IoT	Internet of things
LTE	Long Term Evolution
NBd	Nationale Bewegwijzeringsdienst
NDW	Nationale Databank Wegverkeersgegevens
NHTSA	National Highway Traffic Safety Administration
OBU	On-board unit
SIM	Subscriber identity module
TIM	Transparent Intersection Management
UML	Unified Modelling Language
V2V	Vehicle-to-Vehicle communication
V2X	Vehicle-to-X communication
ViM	Vlaams instituut voor Mobiliteit
WI-FI-P	IEEE 802.11p/ITS-G5

1 Introduction

General Motors had an exhibition called Futurama, which they presented at the 1939 World's Fair in New York. At this exhibition promised General Motors that the United States would have an automated highway system and said that there is a fundamental revolution coming in the transportation of passengers and freight (Anderson et al., 2014). 75 years later, the automated vehicle technology is going to be reality.

Automated vehicles have a huge potential for more productivity in the vehicle and to increase traffic safety, reduce costs of congestion, energy consumption and pollution. They can force changes in vehicle ownership and patterns of land use and may create new markets and economic opportunities. In addition, it will give new forms of freedom of mobility to those stakeholder groups who have been limited so far in their choice of mobility mode, such as blind people. However, policymakers are only starting with the big changes, which automated vehicles predict. They face many questions, the answers to which will be influential with the adoption and impact of automated vehicles. These include everything from how this technology should be permitted on the roads to the appropriate liability regime (Anderson et al., 2014). This thesis will give some answers to these questions.

The potential market outlook for the automated vehicles is quite good. Some researches in the Netherlands and the United Kingdom affirm that around 40% of the population would use an automated vehicle if it was available (Kluiters & Hengstz, 2015; Wockatz & Schartau, 2015). Another research revealed that 22% where not willing to pay more than zero dollar for a fully automated driving system. 5% of the population would be willing to pay more than 30,000 dollars (Kyriakidis, Happee, & de Winter, 2015).

1.1 Problem definition

The federal government of the Netherlands invests yearly two thousand million euro in the highway network. Flanders invest yearly 597 million euro in the road network. Like it is showed, there are currently a lot of investments done in the road network (Ministerie van Financiën, 2014; Vlaams Parlement, 2015). In the Netherlands, Rijkswaterstaat invests 60 million euro per year on dynamic traffic systems. 22 million on traffic signals. In addition, local and regional road authorities spend large sums of money in road network and traffic management systems (Frommé, 2016).

The first automated vehicles will be soon made available for public. It would be good for governments to know if the needs of the automated vehicles suit to the current investments in the road network. There is a possibility that the current policy does not suit. This is because of the fact that current investments shift from infrastructure to telematics. If that is the case, it means that many investments may become obsolete. These questions arise in several governments like in the Netherlands and Flanders (Litman, 2014).

1.2 Objectives

The main goal of this research is to give recommendations about how to make current investments in the road infrastructure and traffic management systems sustainable for the future, in the light of the transition towards a mobility system with fully automated vehicles.

- Gives an overview of the current research and developments to improve the communication between policy makers and vehicle manufactures, as well as between policy makers and road authorities.
- Gives an overview of the current research and developments to improve the communication between policy makers and road authorities.
- Contributes to the current research by filling the gaps of the research with the use of a traffic model.
- Gives guidelines to the policy makers how to implement this research in their policy.

1.3 Boundaries

This study focuses on the policy in the road infrastructure in function of the automated vehicle. Road infrastructure includes the road, the roadside systems and the digital infrastructure. The economic and technical aspects are taken into account. The thesis will develop several scenarios since the future is hardly predictable. The report is mainly about the region Flanders and the Netherlands because most of the interviews are conducted here. The stakeholders of this research are the municipality Helmond and Rijkswaterstaat from the Netherlands and Ministerie van Openbare Werken from Flanders. This study focuses on level of automation three, four and five. More explanation about these levels is in part 2.1. It is focussing on these levels because till now automation level two is achieved and the biggest changes in infrastructure probably will happen in higher levels of automation. In addition, the situation of mixed traffic will be intended because the next 50 years will be in this situation. This investigation will not focus on the human or legal aspects of the automated vehicles.

1.4 Stakeholders

This report is intended for governments which wonder how to prepare the road infrastructure for the introduction and deployment of automated vehicles. This report gives recommendations to the governments how to deal with automated vehicles. The stakeholders are listed below:

- Road authority: Road authorities are most of the time the governments. This report gives an overview, how road authorities should invest to make policy suitable for the future. Gert Blom from municipality Helmond and Rijkswaterstaat in the Netherlands and Kristof Rombaut from Ministerie van Openbare Werken in Flanders are cooperating with this investigation.

- Automated vehicle manufacturers: They can use the recommendations and adapt it to their vehicles. Therefore, if they develop an automated vehicle, the road authority will easier approve it.
- First tier suppliers: they deliver automated vehicle systems and components to the car producing companies. Therefore, they need these recommendations to adapt to the different needs of the vehicle manufacturers.
- Road construction companies: The construction companies can use the recommendations to adapt the infrastructure which is necessary for the automated vehicle.
- Traffic management hardware and technology suppliers: There will be more communication and to capture all this data, there is need for new soft- and hardware.
- Road users: All road users pay taxes and with that money the road authority invests it in the roads. Therefore, if the road authority follows the guidelines in this report the investments can happen in a better way.

1.5 Research questions

After the problem definition and objectives are formulated, the research question is coming up now. The main research question is; “how can the current investments of the road network be made sustainable for the introduction of automated vehicles?” To answer that question there are sub-questions formulated, which are listed below.

1. How will automated vehicles get static and dynamic information about the infrastructure?
   This question focuses on the communication between vehicles, other road users and infrastructure. It is divided in two subjects. Firstly, how can automated vehicles get static traffic information. Static traffic information is imported from an online server and deals with issues such as the place of the road and the amount of lanes. The traffic control centre can change it in an online database to get it up to date. For example, if there is another regulation or a change in the alignment of the road, there is a need to update the maps.
   The other part is about how automated vehicles get dynamic traffic information. For dynamic information, there is vehicle-to-vehicle (V2V) communication about instantaneous happenings like an accident. However, there will be a kind of traffic control centre to collect, analyse and distribute all data. If the government decides to lower the speed on highways because of smog, the traffic control centre can distribute that information quickly. Dynamic traffic management is a good way to optimise the traffic flow.

2. What is the future of traffic signs?
   Some traffic signs can disappear earlier than others can. It depends on the level of automation and the amount of automated vehicles. It is depending on the evolution of the automated vehicles. However, at the end most of the traffic sings on certain road segments will disappear.
3. What will be the role of the government in function of the automated vehicles?
   There will be several things discussed in this part like what will be the role of the road authority. In addition, how the infrastructure will change in the future. There will be discussed if there is a need of a traffic control centre, the need to collect all data gathered from changing roads and the need to collect data and analyse it. For example, to improve the road network, for short term changing like speed. Another example among many is that the traffic centre can send a signal to all vehicles if there is too much smog that the maximum speed is lowered. There is need for regulatory agency to arrange clearance for a direction. The last part is about the enforcement methods, which possible can change.

1.6 Structure report

This chapter gave an introduction about the subject as well as the objectives, boundaries stakeholders and research questions. In chapter 2, there is a literature investigation about the automated vehicle itself, the communication, the infrastructure, the traffic signs, the role of the government as also some application areas. In chapter 3, the research method will be explained how to continue the investigation. First there will be spoken about the data collection, after that the data analyses and the timing. In chapter 4, there will be an analysis of the results obtained, this includes. WI-FI-P versus 4G, some case studies and the declaration of Amsterdam. In chapter 5, the conclusion and recommendations of this report will be discussed. In chapter 6, the recommendation of the future work is explained and some improvements for the current research.

2 Literature investigation

This part contains an overview of the current literature. Furthermore, it contains the interviews with several stakeholders. It will start with the general explanations about automated vehicles, afterwards the different kinds of communication. Then the different infrastructures will be discussed also as the traffic signs. At the end the role of the government will be discussed as also some applications.

2.1 Automated vehicle

Automated vehicles are the main topic of research of this thesis. This part will start with the definition what automated vehicles are. Afterwards, the pro and cons will be discussed. Then the current situation of research of automated vehicles is described. At the end there is something written about the future expectations.

2.1.1 Definition

According the National Highway Traffic Safety Administration (NHTSA) in America automated vehicles are vehicles that at least have some facets of a safety-critical control functions occur without direct drivers help. Vehicles that provide safety warnings to drivers but do not execute a control function are not considered as automated (National Highway Traffic Safety Administration, 2013). There are different levels of automated vehicles. Level 0 involves no automation, level 1 is driver assistance, level 2 is partial automation, level 3 is conditional automation, level 4 is high automation and level 5 is full automation. The different levels are explained below (see Figure 1).

Level 0 – No-automation: There are no systems that have authority over braking, steering or throttle. The driver has control of the primary vehicle controls at all times. He is exclusively responsible for safe operation of all vehicle controls for monitoring the roadway.

Level 1 – Driver assistance automation: This type of automation means that there implicates one or more specific control function. If there are multiple functions, they operate independently. The total control is in hands of the driver and is exclusive responsible for safe operation. The driver can choose to give away authority over a primary control, the system can provide control to help the driver in some situations or the vehicle can automatically assume authority over a primary control. The vehicle may have multiple capabilities, but it does not replace driver alertness and does not assume driving liability. The automated system may controversy the driver in operating one of the controls.

Level 2 – Partial automation: This includes automation with minimal two essential control functions designed to work together to assist the driver. Vehicles at this level of automation can use shared authority when the driver let go active primary control in certain situations. The driver is still responsible for safe operation and monitoring the road and should always be available for control and on short term. The system can abandon control with no signal and the driver must be available to take over the vehicle.

Level 3 – Conditional automation: This level enables the driver to release total control of all critical functions under some conditions. In those conditions, the driver has to rely on the vehicle that it will make the ride decisions. If the vehicle cannot handle the situation, it needs to give back the control to the driver. The driver should be available for some control, but with long comfortable change times. The vehicle should make sure that there is a safe operation during the automated driving mode.

Level 4 – High automation: In this level, the driver should not resume to actively driving. However, in some areas full automation is available. The key challenge is the transfer from an automated driving place to a non-automated driving place.

Level 5 – Full automation: In this level, the vehicle will perform all critical driving functions and monitor conditions for the whole trip. Such a design expects that the driver provides the destination, but the driver is not anticipating being available for control during the trip. This includes both full and empty vehicles. Safe operation rests exclusively on the automated vehicle (Anderson et al., 2014; SAE, 2014).

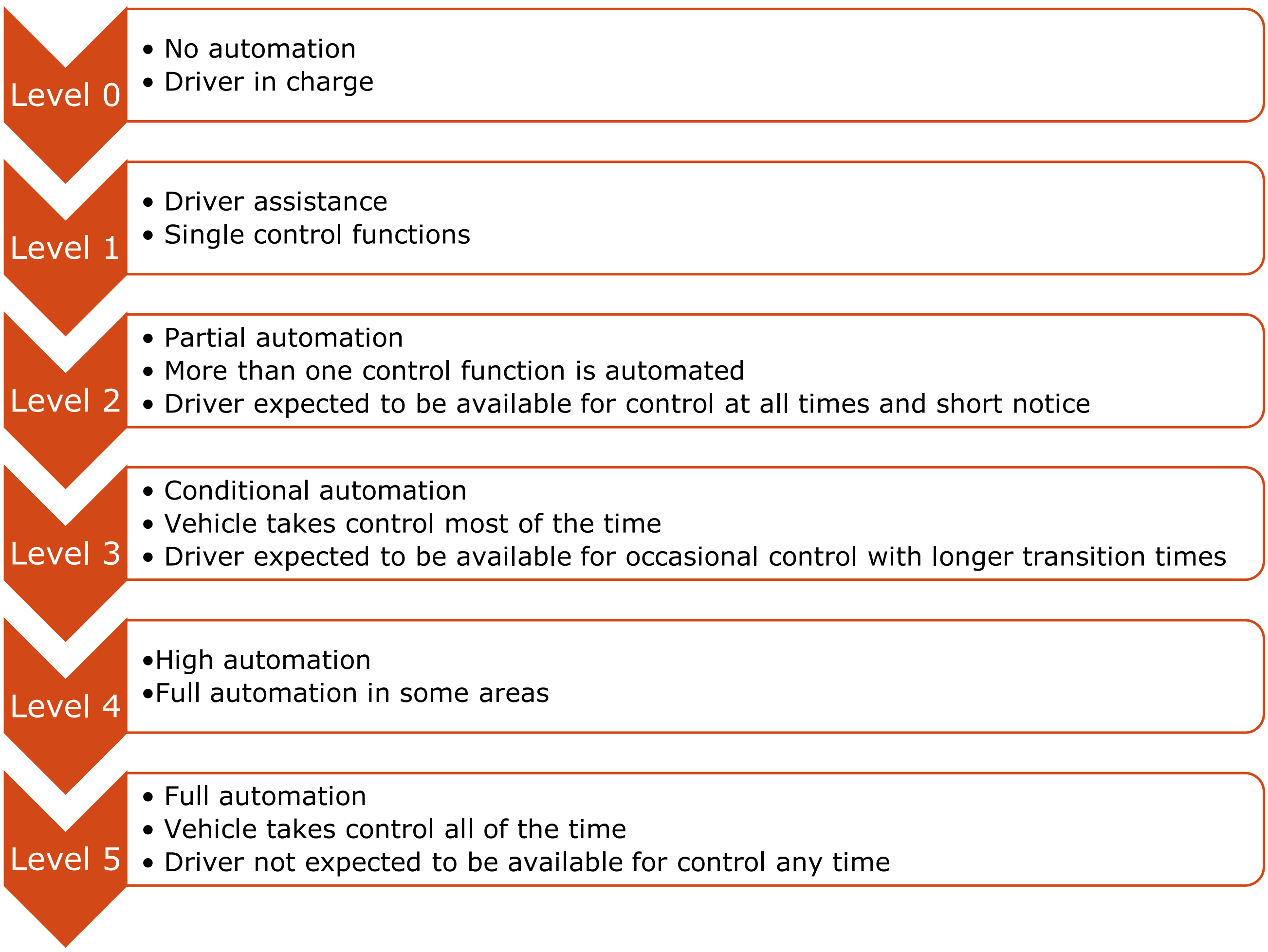


Figure 1 Levels of automation (SAE, 2014)

2.1.2 Autonomous vehicle vs. connected vehicle

Nowadays many terms are used simultaneous without knowing what they exactly mean. Examples for such synonym terms are autonomous, connected, self-driving and automated vehicles. To give a clear overview Figure 2 distinguee between four types.

The x-axis distinguee between autonomous and connected vehicles. An autonomous vehicle acts independently without interaction of other vehicles. It has a lot of technology on board so it can navigate safely though the traffic. A connected vehicle uses a lot of communication between vehicles and infrastructure along the way. It uses several data sources like the internet, other vehicles information to navigate safely though the traffic. It has less sensors than the autonomous vehicle (Maréchal, 2015; Roche, Langton, & Aughney, 2007). On the y-axis the level of automation according to Figure 1 is drawn. The four different are explained here:

1. Automatic autonomic vehicles: They act independently of V2V or V2I communication. The vehicles use on board sensor technology. The vehicle processes this information to get a good image of the surroundings. They use artificial intelligence and robotic information to drive smoothly. Therefore, the vehicle is learning why it is driving. (Campbell, Alexiadis, & Krechmer, 2015).
2. Autonomic manual vehicles: These are the vehicles with level of automation 0 and 1. They can have some kind of automation system but the use of that system is manual. Vehicles act independently from other vehicles. There is no information transfer between vehicles.
3. Automated connected vehicles: vehicles can talk with each other and with the infrastructure. The data exchanged between vehicles would include parameters like location, direction, braking, speed and loss of stability. The data with the sensors give an indication of the threats around the vehicle. And the vehicle will take action when there is a threat.
4. Connected manual vehicles: These vehicles are connected with other vehicles and advices the driver. Therefore, the main driving task stays with the driver (Campbell et al., 2015).

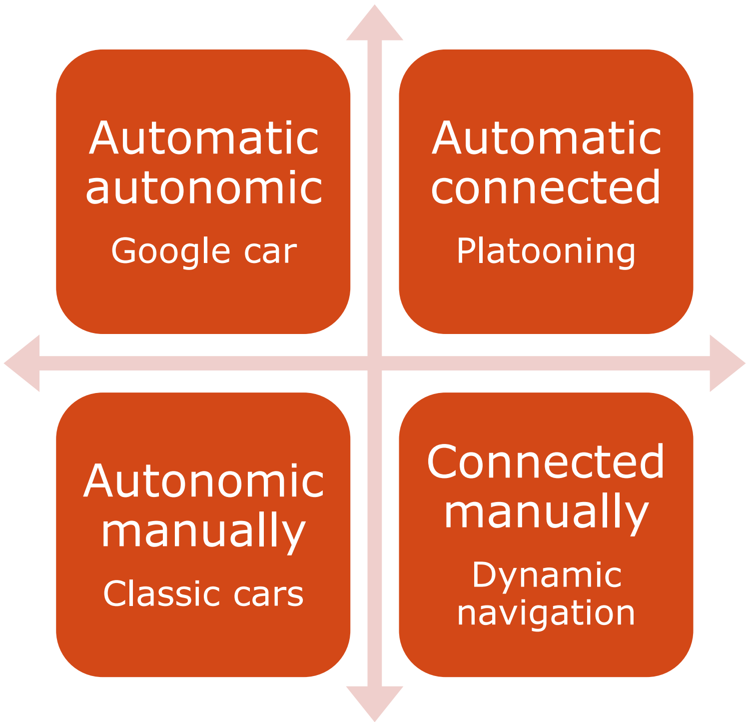


Figure 2 Division of several kinds of self-driving vehicles (Blom, 2015)

Future scenarios are showing that the connected vehicle and the automated vehicle will merge in a connected automated vehicle that has the benefits of both types of vehicles (see Figure 3). This report there is about automated vehicle that means the automated connected vehicle.

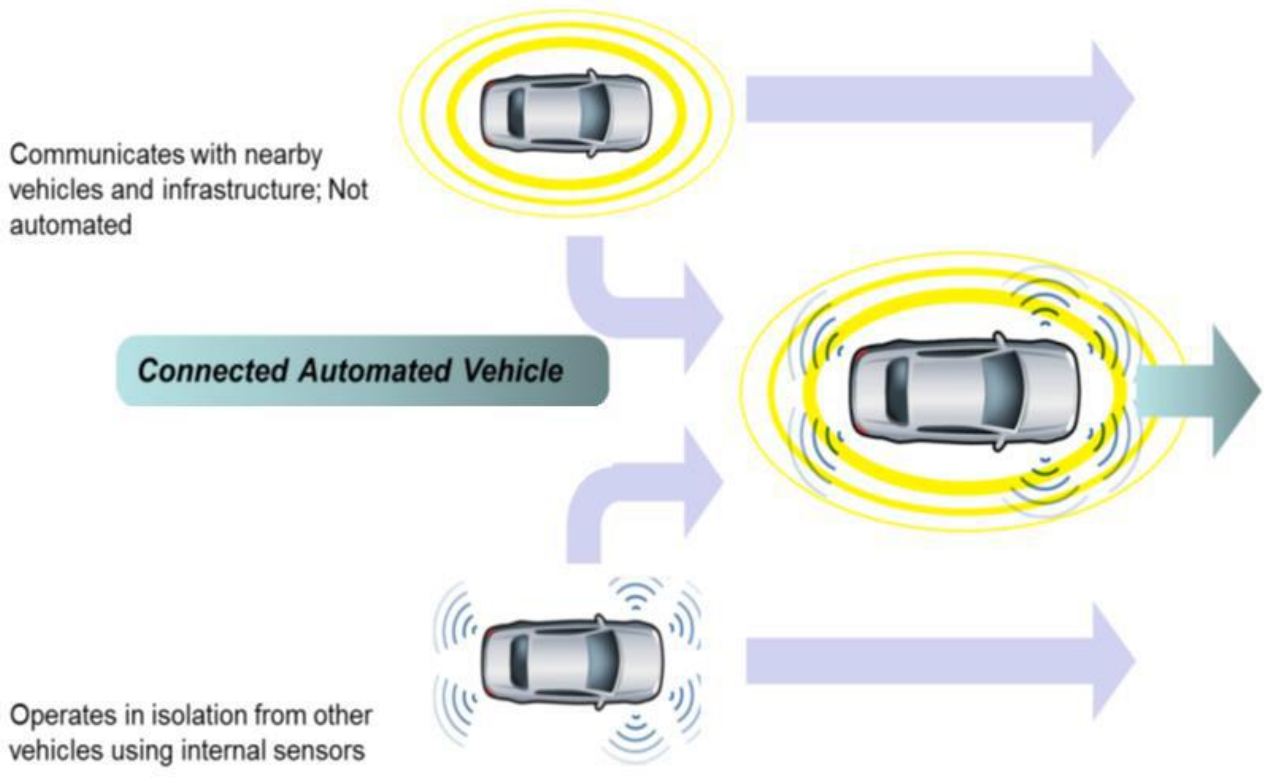


Figure 3 Connected automated vehicle (Alkin, 2015)

2.1.3 Current situation

Currently, the manufactures are at the level of combined function automation (see Figure 1). Many systems are already commercially available and cooperate with each other. There are many intensive research and development projects going on to make the automated vehicle a success (Hoogendoorn, Arem, Happee, Espinoza, & Kotiadis, 2013).

In the Defence Advanced Research Projects Agency (DARPA) challenges, there are many automated experimental vehicles developed. Others are already using automated vehicles based on dedicated and restricted infrastructures. The infrastructure can be adapted to the automated vehicles (Hoogendoorn et al., 2013).

The question when automation will be available in vehicles for consumers remains, although automated driving tests are conducted. To make sure that automated vehicles drive safely and efficiently on public roads, several challenges have to be solved (Hoogendoorn et al., 2013).

2.1.4 Future expectations

The future of the automated vehicle looks bright. There are many developments going on with big budgets. What are the future expectations about the implementation of the automated vehicle? Figure 4 shows the personal estimation of the market introduction by Steve Shladover. He believes that the level five automation will not be implemented within the next 50 years. However, according Shladover, within the next 15 years the level one and level two are implemented and all new vehicles on the market are apparelled with this technology. There will be some vehicles with partial levels three, four and five but they are rarer and not available for the public (Alkin, 2015).

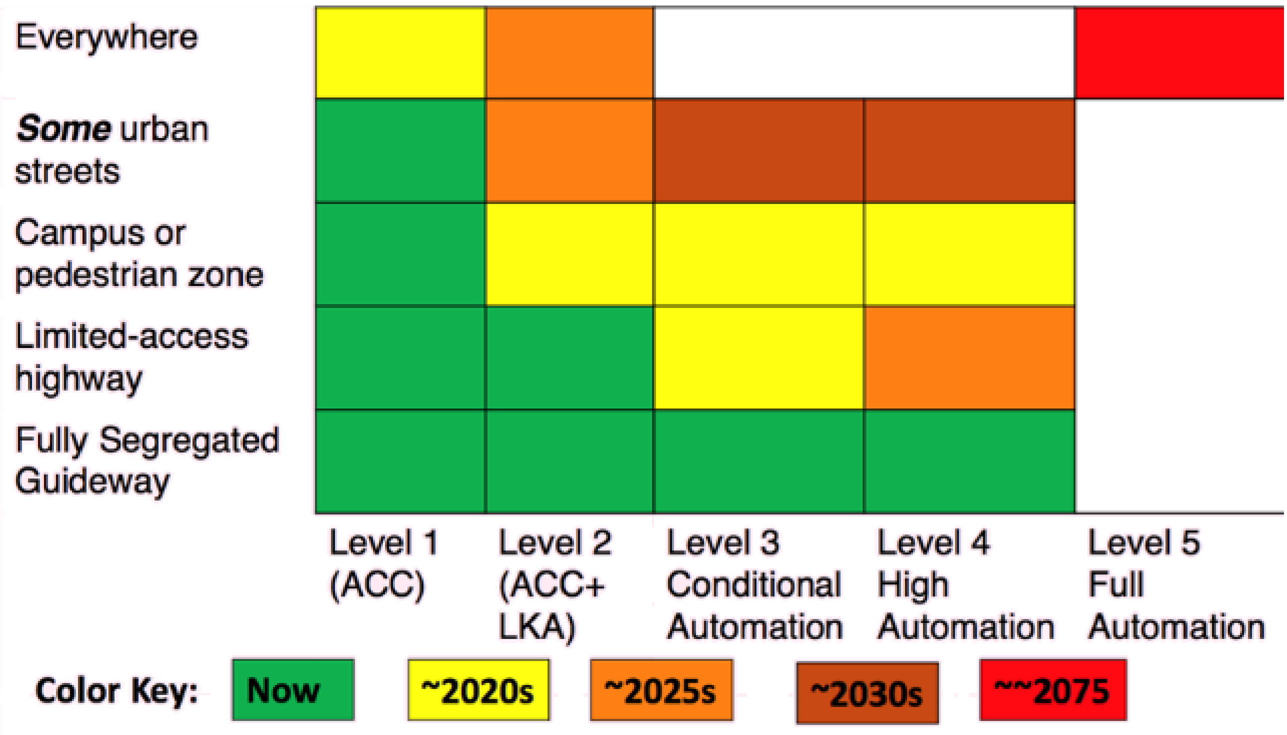


Figure 4 Personal estimate of market introduction by Steve Shladover (Alkin, 2015)

If automated vehicle implementation follows the patterns of vehicle technologies it will take three decades to dominate vehicle sales and two more decades to dominate vehicle travel and even at market saturation it is possible that a significant portion of vehicles and vehicle travel will continue to be self-driven (see Figure 5). (Litman, 2014)

The implementation of automated vehicle could be slower and less complete than these predictions. Technical challenges may be more difficult to solve than expected, fully self-driving vehicles may not be commercially available until the 2040s. This is even fast compared with Shladover's prediction. (Litman, 2014)

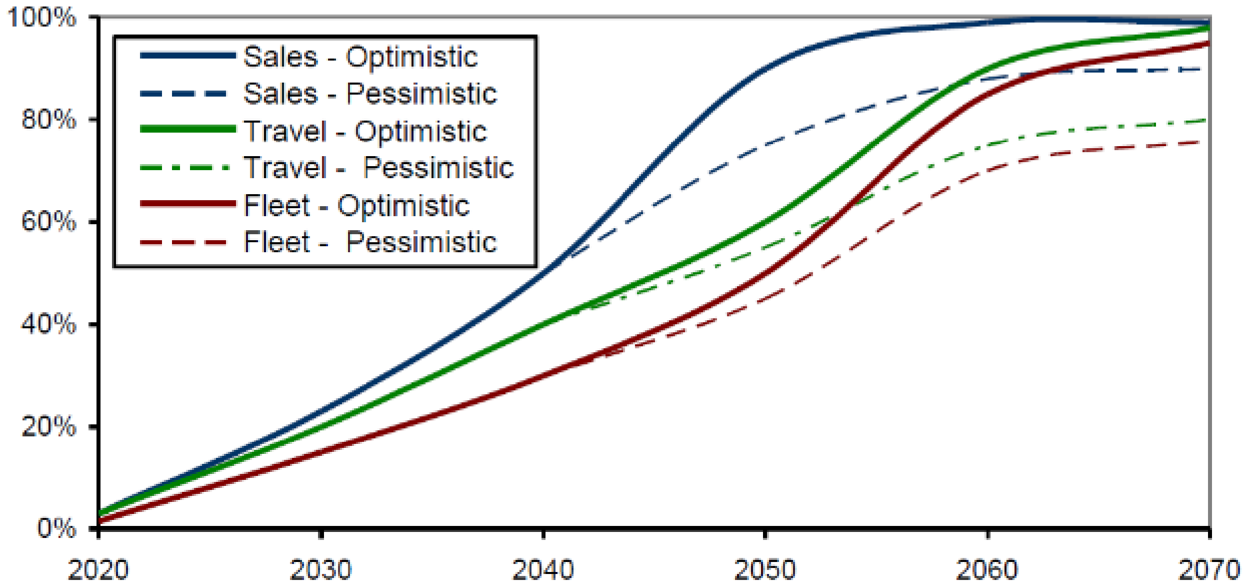


Figure 5 Predictions implementation automated vehicles (Litman, 2014)

On the other hand, developments in information technology and artificial intelligence are going rapidly, with an exponential growth in computer speed. With the help of artificial intelligence, automated vehicles will become quickly more intelligent and hence capable of making decisions more accurate compared to human drivers (Blom, 2015).

2.1.5 Benefits

Currently there is a hype going on about automated vehicles. This is mainly due to the benefits that are discussed below. Nevertheless, the automated vehicle still has to make the promises true because there has not been a fully automated vehicle yet.

Automated vehicles have possibilities to improve flow efficiency, safety and reduce gas emissions. The following improvements are envisaged:

- Automated vehicles can reduce congestion by 50% assuming the current levels of traffic flow. It is because of the better anticipation towards the traffic conditions and thereby reducing the probability of breaking and acceleration. V2V communication will provide benefits in the prevention of congestion and the management of traffic flow in the network (Hoogendoorn et al., 2013).

- The capacity can increase with more than 100%. This is because of the shorter follow distances, platooning and less turbulence in the traffic (Hayes, 2011; University of California, 1997).
- Automated vehicles would reduce accidents involving vehicles by 80-100%. Advanced technology will be used to detect and respond to hazards and vulnerable road users faster and more adequately than the normal driver. If there still happens an accident the vehicle can calculate the ideal crash angle if it hits against something, it will reduce the seriousness of the crash (Campbell et al., 2015; Hoogendoorn et al., 2013; Read, 2011).
- Automated vehicles will improve energy efficiency by 20% through efficient and precise speed control. The reduced congestion leads to an improved energy efficiency through a reduction in speed variation. Platooning will decrease the energy consumption (Campbell et al., 2015; CROW-KpVV, 2014; Hoogendoorn et al., 2013; University of California, 1997).
- Reduced driver stress, because of the fact that automated vehicles can do everything on their own, the driver can rest and work while traveling (Litman, 2014).
- Reduced driver costs, the cost of drivers for commercial transport and taxis is lower because a computer does it (Litman, 2014).
- Mobility for non-drivers will increase. The system can provide independent mobility for non-drivers and therefore reduce the need to drive non-drivers and to subsidize public transport (Litman, 2014).
- More efficient parking, vehicles can drop off their passengers and find a parking space. It is an increased convenience and reducing total parking costs (Litman, 2014).
- Support shared vehicles. Vehicles can be shared easily because not everyone needs to drive on the same time (Litman, 2014).
- Automated vehicles can reduce the energy consumption because vehicles drive on electricity and the vehicles are way lighter. This is possible because the chance of the crash is not that high and they can use lighter material (Anderson et al., 2014).

2.1.6 Disadvantages

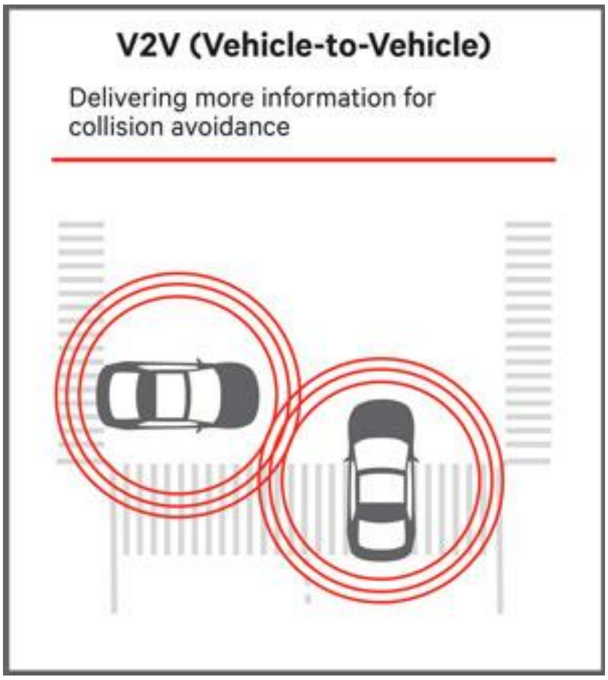
There are some disadvantages and problems to solve before automated can be fully implemented. These challenges are listed here:

- Shift of the costs, the implementation costs of additional software, equipment, service and maintenance (Litman, 2014).
- Additional risk is implemented because it is a new technology and it is not known if there is a failure. Level of automation 3 is a bit hard to implement. Ford wants to skip level 3 because it presents one of the biggest challenges with this technology: How to transfer control from the computer to the driver, particularly in an emergency. Vehicle manufactures need to find a way how to deal with this problem (Davies, 2015).
- Security and privacy concerns are present due to the fact that consumers do not know what companies do with the information and if the information is stored safely without a chance of a digital burglary. (Litman, 2014)
- Increased external costs, because of the convenience of the automated vehicle more people will use it. Therefore, there will be more vehicles, which affect the environment and the parking spots. (Litman, 2014)
- Social equity concerns. The automated vehicle can have unfair impacts, for example by reducing other modes' convenience. (Litman, 2014)
- The employment and business activity will be reduced. Driver jobs will decline and there will be less demand for vehicle repairs due to reduce crashes. (Litman, 2014)
- Other planning emphasis, focusing on automated vehicle solutions may discourage communities for implementing conventional bus cost-effective transport projects such as pedestrian and transit improvements, pricing reforms and other demand management strategies (Litman, 2014).
- Human behaviour barriers, people tend to be reluctant to changes and may seem reluctant to give over control "of the steering wheel", reducing the "Freude am Fahren" (Blom, 2015).
- It could be that there are environmental because people can maybe use less public transport
- Changing law is a long process, so it is not easy to do.
- In every country there is different laws and signs. So it is hard if someone will pass the border.

2.2 Communication

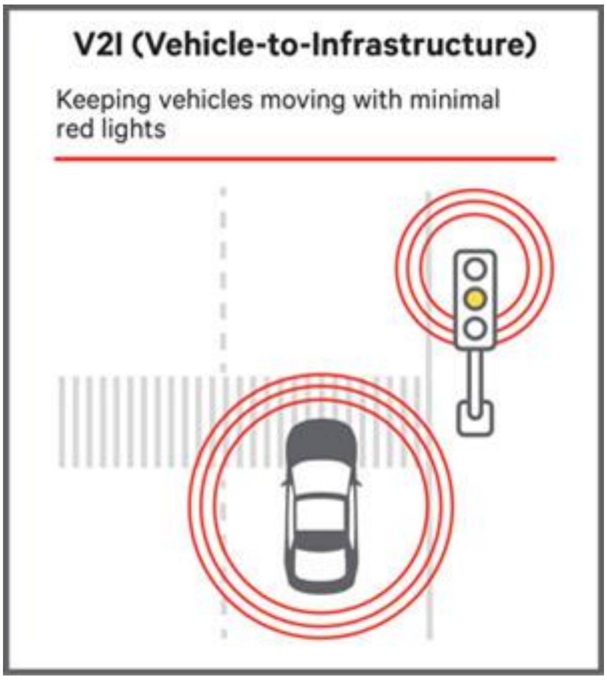
There are several ways to transfer data to and from moving vehicles. This will play an important factor in the development of automated vehicles in different ways. Vehicles may first use cloud-based resources. Like that, automated vehicles continually will update maps, which rely upon sensor data from other vehicles. If a vehicle's sensor has a malfunction it might be able to rely upon another vehicle's sensor. Secondly, the development of Dedicated Short-Range Communications (DSRC) applications is going fast, that would allow vehicle to X communications (V2X). Third, there is an inevitable need for software updates, which will require communications. Infotainment content will increase because full-time driving is no longer necessary (Anderson et al., 2014).

There are several possible ways of communicating with the automated vehicle. V2X is the umbrella term for at least vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P) and vehicle-to-cloud (V2C) communications. Vehicles will share information with each other and the surrounding (Qualcomm, 2015). Below are the definitions of the communication types for the better understanding the terms.



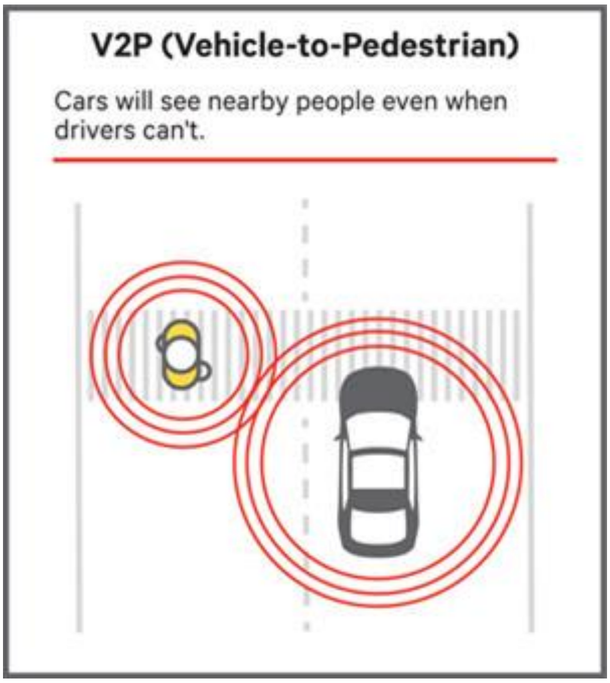
V2V (Vehicle-to-Vehicle): This is communication between vehicles. It supports safety systems with collision avoidance capabilities that benefit drivers, passengers and everyone who shares the road. Other information can be transferred such as information of road conditions ahead (Schaffnit, 2010).

Figure 6 Vehicle-to-Vehicle communication (Qualcomm, 2015)



V2I (Vehicle-to-Infrastructure): This is communication between infrastructure and the vehicle. It offers a variety of applications, including on-the-road information, safety and interactivity. In addition, the traffic flow can increase if they communicate with traffic lights. Traffic signs can have a sensor at road works so the vehicles know if they can pass or have to slow down. There is less stopping at roads (Schaffnit, 2010).

Figure 7 Vehicle-to-Infrastructure communication (Qualcomm, 2015)



V2P (Vehicle-to-Pedestrian): This is the communication between two road users. Both can receive warnings or signals to prevent anticipated collisions. Pedestrians receive alerts via smartphone applications or other connected wearable devices. This application is also possible for motorists and bicyclists. The main problem about this technology is that it is not the same as V2V. That is why there is need for more investigation (Honda Motor Co. Ltd., 2015).

Figure 8 Vehicle-to-Pedestrian communication (Qualcomm, 2015)

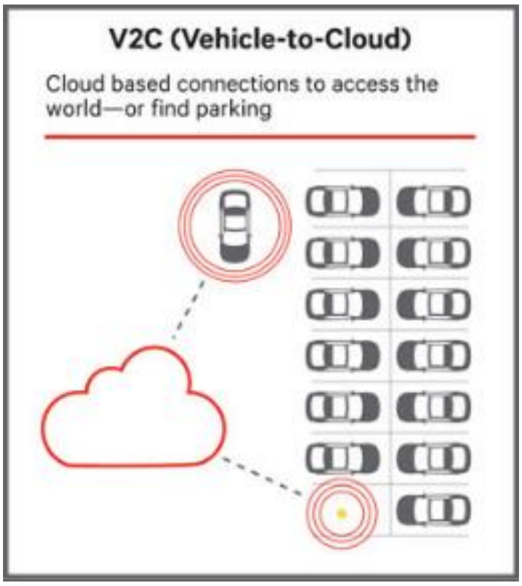


Figure 9 Vehicle-to-Cloud communication (Qualcomm, 2015)

V2C (Vehicle-to-Cloud): This is information transfer between the cloud and the vehicle. Several services make driving both more efficient and enjoyable.

2.2.1 Current developments

V2X communication based on IEEE 802.11p/ITS-G5 (WI-FI-P) has developed to a mature technology. Open, international standards play an important role to achieve interoperability. Currently, two sets of standards for V2X communication exist; the Connected Intelligent Transportation systems (C-ITS) standards from European Telecommunications Standards Institute (ETSI) and European Committee for Standardization (CEN) in Europe and Dedicated Short Range Communication (DSRC) in the United States.

For automated driving, the V2X communication supports driver assistance and partial automation, where the driver is still required to resume manual control. For higher automation levels, there is a need for two main new functionalities: Dissemination of sensor data and cooperative manoeuvring. Vehicles transmit aggregated information; the dissemination of sensor data has higher demands on data rate, reliability and latency. In addition, vehicles typically send data to all neighbours in their reach. Cooperative manoeuvring may imply to negotiate manoeuvres between two vehicles or within a small group of vehicles. These functionalities can be realized with WI-FI-P based systems. The 5G cellular system promises great enhancements in functionality and performance. With the introduction of proximity services into the cellular architecture in the standards, the foundation for direct communication among devices as a key functionality for vehicular communication was laid. Alternatively, the inherent support for multiple radio technologies in 5G potentially allows the integration of WI-FI-P radios into the future 5G cellular systems (Festag, 2015; Meroth et al., 2015).

Another possibility is to use the technology of Bluetooth. It is a wireless technology to transfer data over short distances. Currently, it is used to extend the use of a mobile phone for making it hands-free. Nevertheless, it is possible to communicate between vehicles or infrastructure. This option is particularly interesting since the safety aspect is given. (Anderson et al., 2014)

Rijkswaterstaat already field-tested the WI-FI-P stations and the 4G. However, the response time of the 4G was too high. Now, with a project called "spookfiles A58" they managed to get a time delay of 60 seconds. That is why they choose for WI-FI-P in the ITS corridor in the Netherlands. The WI-FI-P antennas are quite expensive for their range. There is a need to have them everywhere on the road for implementing it everywhere. Many drivers have already a cell phone with internet connection in the vehicle. Therefore, the road authority would like to use that kind of signal because of the cost reduction. It isn't possible yet because of a too slow connection (Hoernig & Schrijnen, 2015; Rijkswaterstaat, 2015).

Most probably, the next decade there will be a hybrid situation, with both WI-FI-P (ITS-G5) as well as 4G/5G cellular communication. Time-critical applications, such as e-call, will merely depend on WI-FI-P, whereas less time-critical applications will be distributed to larger number of users via cellular network (Blom, 2015).

2.2.2 VANET

There is an evolution of Vehicular Ad Hoc Networks (VANET). Such network is meant to distribute information to inform road users of automated vehicles about the road conditions ahead. A VANET exists of sensors, on board units and some roadside units. The data, which is collected, can be sent to roadside units or other vehicles. The roadside unit distributes this data with the ones of other sources like the traffic control centres to other vehicles. It can make sure for some services like booking parking spaces or toll payments. This technology is not yet mature and there is a lot needed to implement this (Vijayalakshmi, Saranya, Sathya, & Selvaroopini, 2014).

2.2.3 Applications

Which kind of information is needed by the drivers is still an unanswered question. Moreover, to whom we need to send which information. Applications can be divided in three types

1. Short message broadcasts
2. On-demand short unicast
3. Large volume content download/streaming

Short message broadcast includes safety applications; they need to send a short notification to a number of vehicles. On-demand short unicast is for example toll payment of searching for a parking spot. The large volume content downloading is for example updating of the maps or watching a movie in the vehicle. All these applications need a different kind of network design. Some need to be secured, others need internet and others only use short distance communication (Krishnan, Holland, & Bai, 2010).

Another unknown area is how to get the internet connection into the car which is necessary because of the e-call that will be required in 2018 by the European Union. According an interview with Coox (2016) will that happen through subscriber identity module (SIM) cards in a mobile device. There are several scenarios how the SIM card can be mounted into the car.

1. There is a SIM card preinstalled in the car by the car manufacturer. The car owner can get a monthly bill for using their SIM card for using the infotainment systems. The car manufacturer can use all data.
2. There is a SIM card slot to put a SIM card in. The car owner can choose the operator.
3. There is a preinstalled SIM card for all car data and safety critical functions and there is a SIM card slot for an own SIM card for all infotainment systems.
4. The last option is that it will work with the mobile phone of the owner. The communication takes place between the vehicle and the SIM card (Coox, 2016).

In an interview with Peeters (2016) from the police. For the police it would be interesting to communicate with the vehicles. They want to use beacons if there is an emergency service is coming. In addition, if they have to stop a vehicle to check it they would like to send a digital signal. Alternatively, if the vehicles need to listen to other commands (Peeters, 2016).

2.3 Infrastructure

Currently, the only infrastructure is the physical infrastructure. However, with the automated vehicles this is changing. The new infrastructure is called the digital infrastructure because a lot of information is going digital to the vehicles.

2.3.1 Physical infrastructure

Between now and 2030, an estimated minimum of €50 trillion in infrastructure investment will be required for global development (Siemens, 2014). Nowadays, the infrastructure is in stage 1.0 and the automated vehicle is in stage 2.0 or 3.0 so investments in infrastructure are unavoidable.

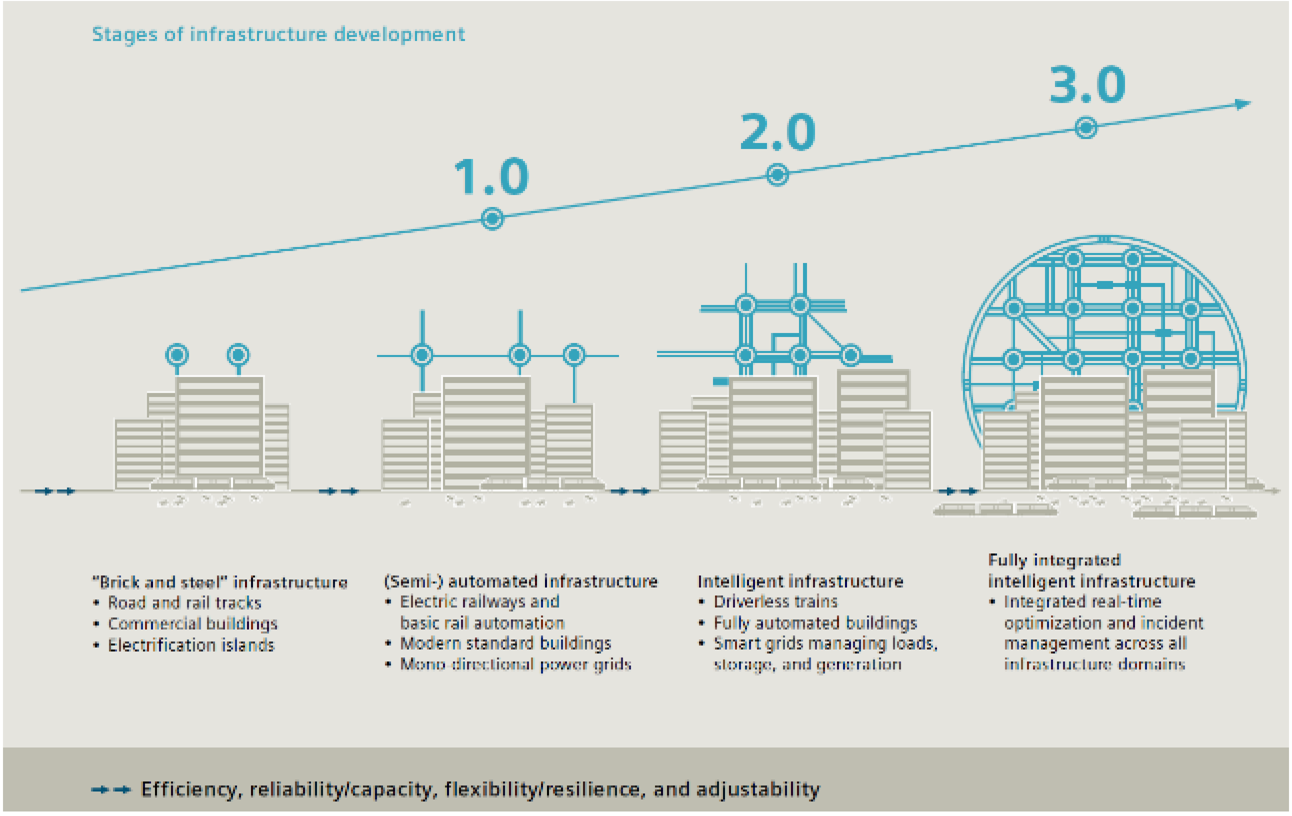


Figure 10 Stages of infrastructure development (Siemens, 2014)

The evolution to fully integrated intelligent infrastructure will change the future vehicles and road systems which support them. The road network today is designed for human drivers who make quite some errors. Therefore, the current roads should be forgiving with extra equipment, which are not required for automated driving. Without the equipment the governments can significantly reduce amounts spend on infrastructure. The capacity will increase without building additional roadways (KPMG & CAR, 2012).

The requirements of automated driving for the physical infrastructure are not clear. To increase the recognition of road markings and traffic signs and signals, they should harmonise them in the world.

In addition, the asset management and maintenance planning can be reduced. Sensors in the vehicles can give information to the road authority if there is need for maintenance. They exactly know how many vehicles have passed there and they can adjust the planning on that information. There are more expenditure to adjust the current roads to automated vehicles (ERTRAC Task Force, 2015).

2.3.2 Digital infrastructure

Digital infrastructure includes static and dynamic representations of the physical world with which the vehicle will interact. Digital infrastructure includes the maintenance of roadway maps and pertinent traffic operations data. This specialised infrastructure could be limited to a manageable set of corridors actually used by a particular urban mobility system (International Transport Forum, 2015a).

There is a trend going on called the Internet of Things (IoT). It refers to the networked interconnection of everyday objects such as vehicles and fridges. With other words, everything will be connected with the internet, many new data are generated. The automated vehicle is a great example (Xia, Yang, Wang, & Vinel, 2012). These large amounts of information are relative new to firms and governments. Big Data is a new concept how to deal with large amounts of information. These large amounts of information are not easy to handle. However, they will play a bigger role in several work fields. The impact of IoT on the automotive industry is still unsure (Shary, 2012).

Car manufactures can use artificial intelligence on the sensors that the automated vehicles can learn from different scenarios. It would be interesting to have an artificial intelligence over all vehicles. Artificial intelligence is a science that tries to let computer do things that require human intelligence. Studies show that the use of artificial intelligence can be interesting for automated vehicles (Grishin, 2011).

Digital infrastructure includes also digital maps. According a European law every member should have a digital map of their country and should always update it (European Parliament, 2010). Currently, some companies are trying to improve the current maps and make them 3D, which is suitable for automated driving. The portable mapping device maker announced in September 2015 the release of 24.000 km of highly automated driving maps. The maps are an accurate type of 3D maps that enables automated vehicles to drive from point A to point B, instead of looking what is on the road in front. These map types provide automated vehicles with a good representation of the road ahead. It can point out lane dividers and speed limits to keep the vehicle in place and allow it to adjust their position. (TomTom, 2015)

The maps differ from the current navigation systems in two aspects. Firstly, maps are from automated vehicles have a much higher accuracy, which is up to ten centimetres. Secondly, the map has is that it has multiple layers. The current navigation layer is used to calculate the route. The location layer uses several techniques to provide accurate map data, which is used to determine the position in a lane.

The vehicle compares the information in the localization layer with the information of the sensors. There is a planning layer, which contains not only attributes but also 3D images. With that information, the vehicle can take action if it is necessary. (TomTom, 2015)

Information from space usage rules can be implemented. These are rules like “no smoking” or “no swimming”. There is critical mechanism through which stakeholders manage their interaction with the environment. If the vehicle is automated the vehicle finds his way, for example to a beach (Samsonov, Tang, Schöning, Kuhn, & Hecht, 2014).

Safety and comfort depend on up to date maps. If that is the case, the vehicle can select the best driving strategy. Companies offer services to keep these maps up-to-date. They will use feedback from vehicles to adjust these maps for up to date information. This information will be transferred to a server, verified and edited in the database. The updated map will be transferred to the vehicles, which can be seen in Figure 11 (Bonetti, 2015; TomTom, 2015).

Information from the infrastructure and other road users can increase efficiency of automated driving. The system can adapt their driving strategy. This function needs integration and validated communication between vehicles. There are some security issues, which have to address as unsecure. This communication may open the system for criminal, abuse or terroristic attacks. If it is not validated the main problem is trust. Do I trust information from another source without validation? That is why there is a need for a road authority. More information about that is in section 2.5 (ERTRAC Task Force, 2015).

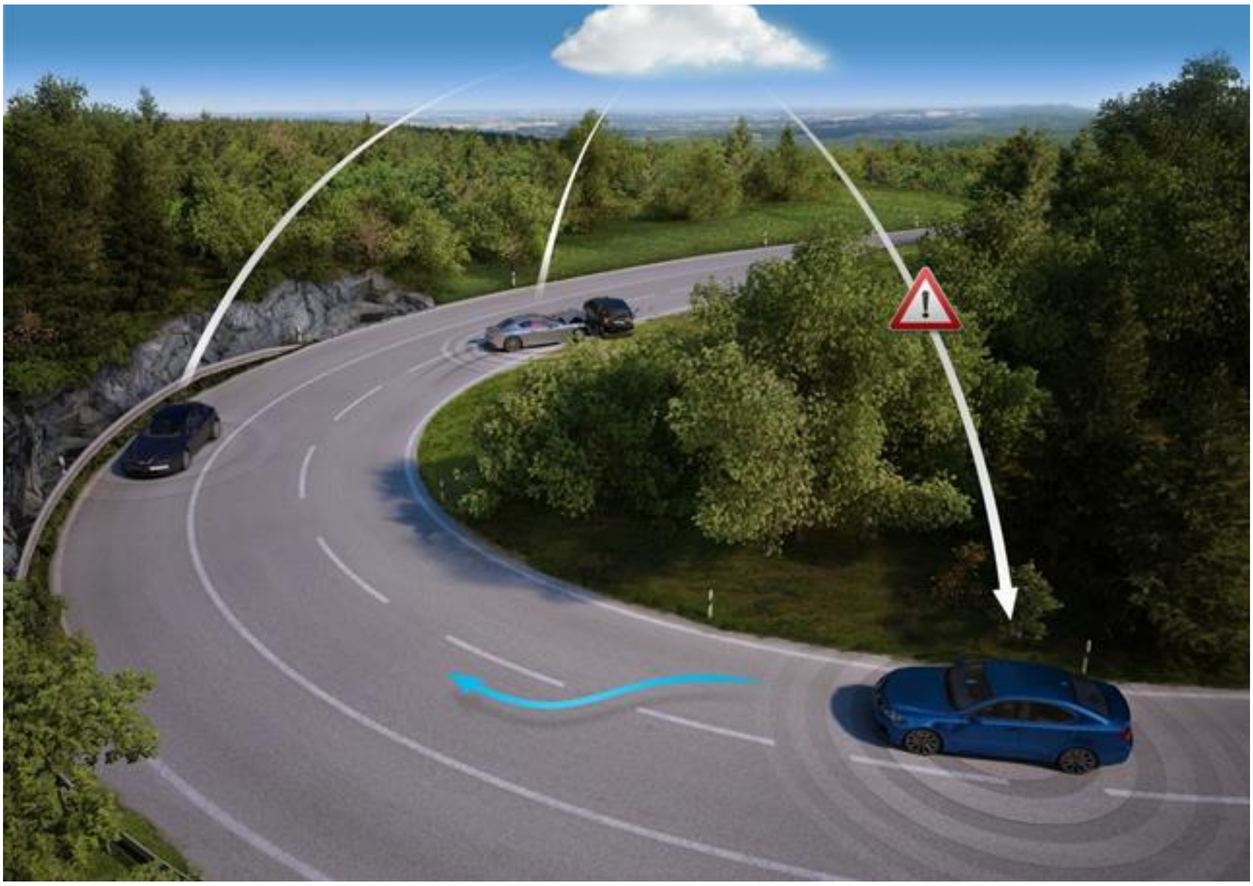


Figure 11 Cloud based communication (Bonetti, 2015)

2.4 Traffic signs and markings

The future of the traffic signs is unclear. Maybe they are not necessary anymore because computers make their own rules or they are all digital. Currently, there are a lot of different traffic signs and markings. In the convention of the United Nations there is a classification of traffic signs (United Nations, 1995).

a) Danger warning signs: they are intended to warn road users of a danger on the road and to inform them;
b) Regulatory signs: they are intended to inform road users of special obligations, restrictions or prohibitions with which they must comply;
    a. Priority signs;
    b. Prohibitory or restrictive signs;
    c. Mandatory signs;
    d. Special regulation signs;
c) Informative signs: they are intended to guide road users while they are travelling or to provide them with other information;
    a. Information, facilities or service signs;
    b. Direction, position or indication signs;
        i. Advance direction signs;
        ii. Direction signs;
        iii. Road identification signs;
        iv. Place identification signs;
        v. Confirmatory signs;
        vi. Indication signs;
    c. Additional panels.

Actual it could be discussed if danger-warning signs are in fact informative signs. This structure will be kept in this investigation (United Nations, 1995).

Currently there are technologies that vehicles can read traffic signs and road markings. To improve the visibility of traffic signs there should be a standardisation. They are necessary for implementing technologies like lane departure warning. Road markings should be maintenance in a proper way that they are clearly visible and not confusing. Governments should use retro-reflective markings that are visible under all weather conditions. They can use the "150 x 150" standard. A good road marking is the one whose minimum performance level under dry conditions is 150 mcd/lux/m² and has a minimum width of 150 mm for all roads; for wet conditions, the minimum performance level should be 35. Another recommendation is to harmonise across Europe the colour and dimensions of lane and carriageway edge markings. A final remark about road markings is to install continuous lines to delineate the edge of the carriageway (EuroRAP & Euro NCAP, 2014).

There are some recommendations about traffic signs. The regulatory traffic signs should be harmonised across Europe with colours, shapes, fonts etc. The vehicles can recognise them easily. In addition, they should be visible good enough. The material used should be durable so it needs less maintenance (EuroRAP & Euro NCAP, 2014).

If all vehicles are automated level 5, probably most traffic signs and road markings can disappear. There is a navigation system in development called Galileo, which is accurate in a few centimetres. This can be interesting because the current GPS is not suitable enough (European Commission, 2011).

Currently, there are around 95.000 signs in the Netherlands, which are maintained by the National signage service (NBd). A public authority maintains traffic signs for road authorities. Currently, they maintain the traffic signs from all highways and some local roads. Some of these signs have a legal impact. If it is replaced, there should be a decision that someone can make objection. Therefore, they are not easily removed. Some of the signage guides drivers to the destination using the socially desirable route. Which is not always the same route as current navigation routes (van den Berg, 2015).

Van den Berg (2015) told in an interview that the first traffic signs that will disappear are the static information traffic signs without any justice value, such as here is a gas station. After that, the most likely is that traffic signs at highways will disappear. However, he assumes that there still remain some signs for bicyclists and pedestrians. To replace the traffic signs of roads, there is a need for something else. One option is roadside systems, which transfer the information to the vehicles, or a cloud based system. More about this implementation can be found in part 2.5 (van den Berg, 2015).

In an interview with Ansar (2015), he thought that the first signs that will disappear are speed limits. They are all in digital maps. The last once will be road construction signs, traffic lights and variable message signs. Nevertheless, in the vision of the researcher this is highly unlikely. In an interview with Soens (2016) thinks that there are other signs necessary than there are nowadays, for example to mark places where it is allowed to drive automated.

In an interview with Peeters (2016) from the police, they say that they want to remove traffic signs. There was a traffic sign database in Flanders, which could have been a great starting point. However, it is not maintained good. Another concern is that drivers do not know the general traffic rules. Therefore, if the traffic signs are replaced by more general rules, it could be difficult to know these rules. Of course, it is easier to programme them in a vehicle. The final concern the police had, was the maintenance of the database (Peeters, 2016).

2.5 Role government

The main task of the government is to make sure that roads are safe and accessible without unbalanced impact on the environment. Therefore, they are responsible for the facilitating of the traffic in their area. One of the ways to do this, is to use traffic management. Another way is to enforce the laws (Ottenhof, 2015).

2.5.1 Road authority

The Netherlands has one of the most intelligent road networks in the world. The government spent a lot of time and money to increase the traffic flow and travel at a save and environmental friendly way. The development of these roads and the roadside equipment should be connected with the automatic vehicle. Because of liveability and safety, it is undesirable that self-driving vehicles choose their route automated. That is why road authorities should think about the self-driving vehicle and how smart roads can be combined with smart vehicles. (CROW-KpVV, 2014)

One example is to use on board sensors from vehicles to gather information about the vehicle's immediate surroundings. The road authority can use this information for their asset management. The key technologies that rely on this external environmental information are blind spot detection systems, lane-departure warnings and rear-parking detection. Cameras and sensors can be arrayed in various positions around a vehicle to provide 360-degree electronic coverage of the vehicle's surroundings. Pairing these different sensors and cameras together can provide information where to maintain a road (Roche et al., 2007).

If vehicles drive with digital maps and drive fully automated, they drive through a digital cloud. Bart van Arem thinks that there will be a redefinition of the role of the road authority. Telecom providers will be the road authority of the future. He thinks that road constructors will have joint-ventures with companies which provide digital services (Beerda, 2015)

2.5.2 Traffic centre

Traffic management is influencing the supply and demand to time and place, with the main purpose of an adequate functioning traffic system. Traffic management is trying to influence the behaviour of the people with traffic information. A traffic control centre is a mean that can be used during traffic management (Boonman, 2015).

The current task of the traffic centre is to guarantee the safety and traffic flow at highways by using dynamic traffic management. Such as dynamic route information panels, signalization above lanes, dynamic overtaking prohibition for trucks and collection of data and give it to several service providers. They guide road inspectors to places where there are disruptions in the traffic safety or flow (Haans, 2016).

In the Netherlands there is started a project for more innovation in the communication with the name ITS corridor. A part of the ITS corridor is to gather anonymised sensor data from passing vehicles. They use a secure WI-FI-P connection. The purpose of this is the use for traffic management. The information is send to the traffic centre, as shown in Figure 12 (Rijkswaterstaat, 2015).

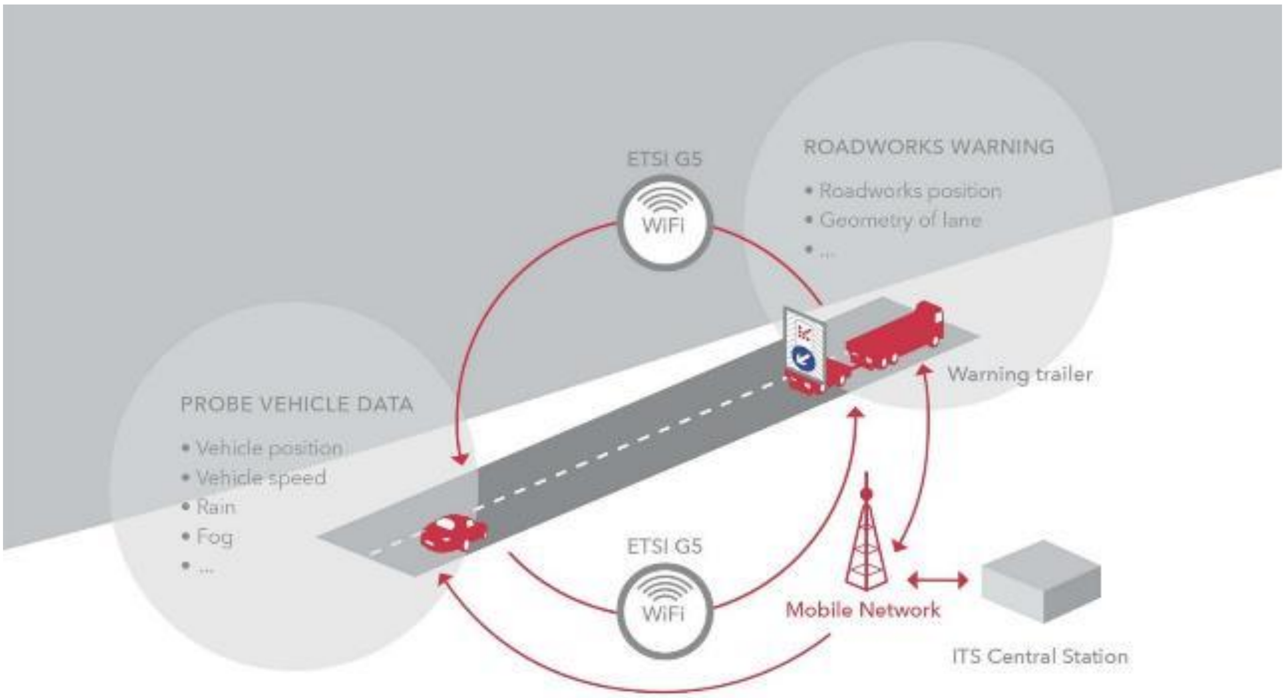


Figure 12 WI-FI connection between vehicles (Rijkswaterstaat, 2015)

The data collection is nowadays done in the Netherlands by the national databank traffic information (NDW). This is a collaboration between the national road authority and provincial road authorities. The aim of this collaboration is to gather all data and distribute it to the several partners to make more innovation (Nationale Databank Wegverkeersgegevens, 2013).

The main problem of the V2X communication is the security and trust. There is still the uncertainty if the vehicle notices wrong sent information. Moreover, will other vehicles trust that vehicle? There are two ways to control if the information sends it correct. The first method is using a VANET that is explained in part 2.2.2. It uses the information from several vehicles to check if the information is correct. An advantage about this system is that it costs no money from the government. A drawback is that some people can hack into the system, take over the whole fleet and spread false information. Another method is to use the traffic control centre to validate the information. This information can get a watermark to get a distinguee between normal information of vehicles and validated information from a traffic control centre. Therefore, foreseen to have a mixture of both methods. source.

In the interview with Peter Hoernig and Laurens Schrijnen (2015), they mentioned that the government always would be in charge of the command and prohibition traffic signs, because they have the legal traffic signs. The other traffic signs could be integrated in the navigation software of cartographers (Hoernig & Schrijnen, 2015).

2.5.3 Enforcement

To ensure that all drivers follow the rules there is need for enforcement. To make the traffic system safer someone should control if rules are followed by the drivers. With the automated vehicle, it could be that all drivers and computers will follow the rules. This is because of the fact that robot's follow the rules which are programmed in their brain. Therefore, the enforcement methods will change dramatically.

There will be many data available for stakeholders. The data from the vehicles will be redirected to the law enforcement agencies. Police can use it to give someone a fine or help with an investigation. There are some concerns with vehicle owners and other stakeholders about this purpose of use of the data. Currently, there is not a lot of literature about enforcement of automated vehicles (Anderson et al., 2014).

In an interview with Peeters (2016) from Centrex, the police knowledge and expertise on traffic enforcement, says there is a big change coming in the enforcement of automated vehicles. In case of an accident, the police would like to have a black box in every car, similar to the ones in airplanes. With this black box, the causer of the accident can be determined, but privacy concerns can play a role: How long is it possible to look back into the system? What to do with possible other violations? There should be a legal framework about what is allowed or not (Peeters, 2016).

Other concern the police had: What to do with incident management? What will happen when there is an emergency service and has to pass? What will happen if an authorised person gives drivers a sign that is the contrary of a normal traffic rule?

Furthermore, hacking cause a big problem. There are two types of hacking, one concerns the tuning of a vehicle, which isn't dramatically but illegal. The other type of hacking is into the control centre and takes control over all vehicles. A possible answer on that is to have a kill switch in every car. In addition, the privacy concerns can play a role. For example, how far can companies go with advertisement?

The most important information which the police wants to have electronically are licence plate, insurance, drivers licence and the annual check if a car is technical all right. These assets they want to check at all time and only further checks if necessary like on accidents.

2.6 Application areas

This part contains areas where the automated vehicle can play a role.

2.6.1 User's

This chapter is about how the life of vehicles drivers will change in function of the automated vehicle. Firstly, it's about shared vehicles and their various possible scenarios. The first scenario is mobility as a service: any time, any place. This scenario assumes that the technology will go up to level five and that consumers would like to share the transportation vehicle. The vehicle comes automatically and drives goes to the destination given. It will check if there is another vehicle going there so drivers can share the vehicle. (Kennisinstituut voor Mobiliteitsbeleid, 2015)

The second scenario is fully automated private luxury. Everyone has his own vehicle from level 5. There is almost no vehicle sharing and the roads are full with platooning vehicles. (Kennisinstituut voor Mobiliteitsbeleid, 2015)

The next scenario is letting go on highways. In the scenario, the vehicles are more level 2 and 3 at highways but people are scared that the technology is not good enough. Most of the people will have their own vehicle. (Kennisinstituut voor Mobiliteitsbeleid, 2015)

The last scenario is multimodal and shared automation. Vehicle sharing is the most common thing in this scenario. The vehicles are at level 2-3. The vehicle will function as cab and it will brings passengers to the multimodal transfer point to take the train to another city (Kennisinstituut voor Mobiliteitsbeleid, 2015).

The value of time will change, because there is possibly no driver anymore and all are vehicle passengers. Therefore, everyone can relax or do something productive. The travel will be less burdensome on a per-minute basis and there will be a reduction of travellers' value-of-time due to their occupants being newly able to perform a wider range of productive activities during traveling (Le Vine, Zolfaghari, & Polak, 2015).

Another application area is taxi pooling. It looks at the impact that the sharing of taxi rides could have on taxi fleet operation. Studies say that the total kilometres will be reduced by 40% with a shared taxi system. It would lead to large cuts in emissions, traffic congestion and costs. In addition, the travellers would pay less. It would be possible to implement a shareable taxi service. The model does not take into account changes in the behaviour of passengers, who could respond to lower fares by increasing their use of the system. Not fully addressed is the potential segmentation of the market, with a low end offering shared rides and a high end offering single passenger rides (International Transport Forum, 2015b; Santi et al., 2014).

Another application is platooning, driving close to another vehicle that it has reduced fuel consumption. The vehicle should be able to keep its position in the platoon with a fixed distance or fixed time difference from the front vehicle. The first vehicle transfers his behaviour through V2V communication. It should smoothly handle vehicles leaving and arriving the platoon.

Dedicated perpetual platoons that allow vehicles to join and leave at specified stations could prove an interesting future application of this technology (International Transport Forum, 2015a).

Automated vehicle offer a great advantage compared with current vehicles. They can ride themselves, meaning that the driver can do something else than driving. The driver can work or sleep, depending on what he would like to do. Therefore, the productive time of a human is increased. The travel time will reduce because of reduces congestion. According Marchetti's law, the travel budget is constant meaning that people will travel more distance. Manufactures can customize automated vehicles to serve the needs of the traveller. The former drivers can be connected to the world while traveling and capable, totally safe or risk of violation, of doing something he would want to do (KPMG & CAR, 2012).

Service intervals given in owner manuals are conventionally based on a defined number of kilometres and it fails to consider user behaviour. Whether the car makes predominantly long or short trips has a major impact on oil consumption and spark plug wear. With connected car, customers can arrange service intervals to correspond with predicted wear and tear and cutting costs and improving safety. This platform delivers valuable information on potential road hazards in real time. In addition, drivers are given useful advice on fuel-efficient driving in heavy traffic, helping them to cut consumption and protect the environment (T-Systems, 2013).

2.6.2 Infrastructure

Parking of vehicles is always a huge problem for the environment. Drivers use vehicles only a few hours a day. They want to park their vehicle as closely as possible in front of their house. This perception will change with the automated vehicle. The cost of current parking places is high. Fregnant & Kockelman estimated that annual parking costs are around $4,500 per parking space in central business districts, $2,500 per parking space in other urban areas and $1,500 per space in suburban locations. Moving a parking space outside of the central business district can save $2,000 in annualized costs. If this space is moved to another suburban location, it can save another $1,000. Automated vehicles use less space than normal drivers do. This reduction in space can lead up to $250 in parking savings realized per new vehicle. Because vehicles can drive on their own to other places, it could be possible that it drives itself to a parking garage or a parking space outside the city. In scenarios where with many vehicle sharing, there is a huge decrease of parking spaces. Information services will make sure that vehicles know where parking places are and there is less search traffic (Fagnant & Kockelman, 2013; Kennisinstituut voor Mobiliteitsbeleid, 2015).

Another future feature is that automated vehicles talk with other vehicles and the infrastructure. Therefore, there could be something different happen on intersections as nowadays like another intersection control protocol. This is much more efficient than the current traffic signals. An example of this is Automated Intersection Management. Automated vehicles can be safer and more reliable than human drivers can. It is designed for the time when all vehicles are level of automation 5.

Nevertheless, it will take a while until that time. There is something called Semi-Automated Intersection Management which can accommodate both automated vehicles and semi-automated vehicles with limited self-driving automation. There will be a mix of human-driven vehicles, semi-automated vehicles and fully automated vehicles on the road in the future. The advantage is that it uses mixed traffic with different types of vehicles. Some results showed that the system could greatly decrease traffic delay when most vehicles are semi-automated, even when few are fully automated. The incremental deployment study shows that traffic delay keeps decreasing as more vehicles employ features of autonomy (Au, Zhang, & Stone, 2015).

Variable pricing is another example for what the infrastructure would make infrastructure more efficient. Imagine that the automated vehicle could calculate the cheapest option for given the time constrains. Higher prices during peak periods would encourage to shift to other routes, modes or times. That system has various advantages. By choosing selectively at certain locations and times, one can influence the level of congestion during peak periods. Variable pricing could reduce the immediate need for building new highway capacity. Planners would have a direct measure of where to build more capacity. When those signals suggested that new capacity would be beneficial, the accumulated toll revenues would provide money to pay for those improvements. Fairness could be improved, as revenue is collected from those who use capacity directly (Council Puget sound regional, 2008).

2.6.3 Commercial services

Currently, vehicle manufactures sell the vehicle and not a lot of services. However, in the future this could change with a rise of particular consumer-oriented products and services. Manufacturers will probably be more closely connected to the users of their vehicles via several contractual and technical tools. Services like end-user license agreements, subscription agreements on the contractual side and advanced telematics on the technical side. They probably will get new revenue streams. Other companies are looking to get more revenue from vehicle automation systems. Currently, there is a lot research going on about this subject. The “everything-somewhere” strategy could more fully embrace a variety of service models. Services can complement with conventional public transportation (International Transport Forum, 2015a; Smith, 2014).

Vehicle telematics applications already use commercial cellular services for voice and data communications nowadays. Chrysler signed an agreement with Sprint Nextel to add its UConnect system to their vehicles. It pulls data through either an embedded data connection or a smartphone. Two of the biggest connected-vehicle platforms, Ford‘s Sync and Cadillac‘s CUE, depend on drivers using their own smartphones to link their apps to the network. Fitchard argued that relying upon users‘ phones was probably the right choice: Long Term Evolution (LTE) is the standard for wireless communications technology and an evolution of the Universal Mobile Telecommunications System standards (Anderson et al., 2014).

Car diagnostics gives original equipment manufacturer access to a treasure chest of information that can be leveraged to help avoid costly product recalls. This data could prove to be particularly useful in vehicle development, where manufacturers are constantly looking at customer's real-world needs.

Recognizing and responding to customer needs are mainstays of service-based sales. Dealerships and repair shops can generate new revenue with car diagnostics. They can harness big data to create offerings tailored to the precise wants and driving habits of their customers. In addition, they can alert clients to potential problems long before there is an actual breakdown. Other information enables repair shops to order the necessary spares in advance, eliminating delays and ensuring cars are back on the road in the shortest-possible time. If the shop knows that something is approaching to the end of its life, it can order these parts before the car arrives for a service (T-Systems, 2013).

3 Research methodology

This chapter contains a description of the research methods by the author of this thesis.

3.1 Data collection

This paragraph contains the data collection method, which is spited into a literature investigation, interviews and traffic model.

3.1.1 Literature investigation

The first part of the data collection is a literature investigation. With the desk research can be seen what other investigators have done in this field of research. There are several places consulted to obtain the sources, like the internet and the library. The literature investigation will not answer all research questions. The next step is to identify these gaps. After identifying these gaps, there will be a research to investigate it.

3.1.2 Interviews

The second step of the data collection are interviews with several stakeholders. There will be an investigation with interview experts in the field of automated vehicles. There already have been some interviews with different stakeholders.

- Gert Blom, innovation manager mobility at the Gemeente Helmond. He was the one who came up with these research questions. There has been a meeting with him at 11 November 2015.
- Kristof Rombaut, Study responsible Intelligent Transport Systems at Agency for Roads and Traffic. There has been a meeting with him at 18 November 2015.
- Ansar-Ul-Haque Yasar, professor at Hasselt University. There have been several meetings with him.
- Tom Brijs, Professor at Hasselt University. There have been several meetings with him.
- Peter Defreyne, Project Manager at Vlaams Instituut voor Mobiliteit There has been a meeting with him at 26 November 2015.
- Bart van den Berg, Director at Nationale Bewegwijzeringsdienst. There has been a meeting with him at 4 December 2015.
- Laurens Schrijnen and Peter Hoernig from Innovatiecentrale and Rijkswaterstaat. There has been a meeting with them at 11 December 2015.
- Yves Coox, Process Architect at Proximus. There has been a phone meeting with him at 5 January 2016.
- Stéphane Galland, Research professor at University of Technology of Belfort-Montbéliard. There has been a meeting with him at 22 January 2016 and a skype meeting on 16 March 2016.

- Gerry Peeters, from Centrex Federale Politie. There has been a meeting with him on 2 March 2016.
- Steven Soens, from Febiac. There has been a meeting with him on 3 March 2016.

These interviews are in-depth investigations and the results are included in the literature investigation.

3.1.3 Traffic model

The third step is to make some case studies with a traffic model called Veins. It is an open source framework specially built for automated vehicles, which uses coupled network and road traffic simulator from both communities. The main goal of this traffic model is to model the communication between infrastructure and vehicles (Garip, Gursoy, Reiher, & Gerla, 2015).

The model consists of several components. The first one is the network simulator. The model compares the performance of different network setups. Through simulation, it makes it possible to recognize and resolve performance problems without field tests. In Veins, OMNeT++ is used which is a modular, extensible, component-based C++ simulation library and framework for building network simulators (Sommer, German, & Dressler, 2011).

The second component is the microsimulation. Simulations of VANET scenarios are concerned with the accurate modelling of single radio transmissions between nodes requires the exact position of the simulated nodes. Therefore, a microsimulation is necessary. The microscopic traffic simulation package SUMO performs the traffic simulation in Veins. It allows simulations of large networks with roads of multiple lanes and junction traffic on these roads. It uses only simple right-of-way rules or traffic lights. The modeller can choose the vehicle types freely with each vehicle following statically or dynamically routes or driving according to a timetable (Garip et al., 2015).

Of course, both packages have to communicate with each other. It happens by extending each package with a dedicated communication module. During simulation, the communication modules exchange commands via TCP connections as well as mobility traces (Sommer et al., 2011).

There are some major advantages of this model compared with uncoupled or purely trace-driven simulation. The network part of traditional simulators is not in it. SUMO looks like VISIM but the extension with OMNET++ is typical for automated vehicles (Garip et al., 2015; Sommer et al., 2011).

The input in the model is a database with 2000 vehicles that are available by the supervisor. The traffic model is used in this research. There will be some scenarios and see what is the impact of the V2V communication.

- Difference communication, non-communication
- Difference WI-FI-P and 5G
- Difference presents of traffic signs

Unfortunately, due to the lack of programming skills it was not possible to make several case studies using the traffic model Veins. Nevertheless, this is still interesting to investigate and someone else still can do it. The several case studies are explained in chapter four.

3.2 Data analysis

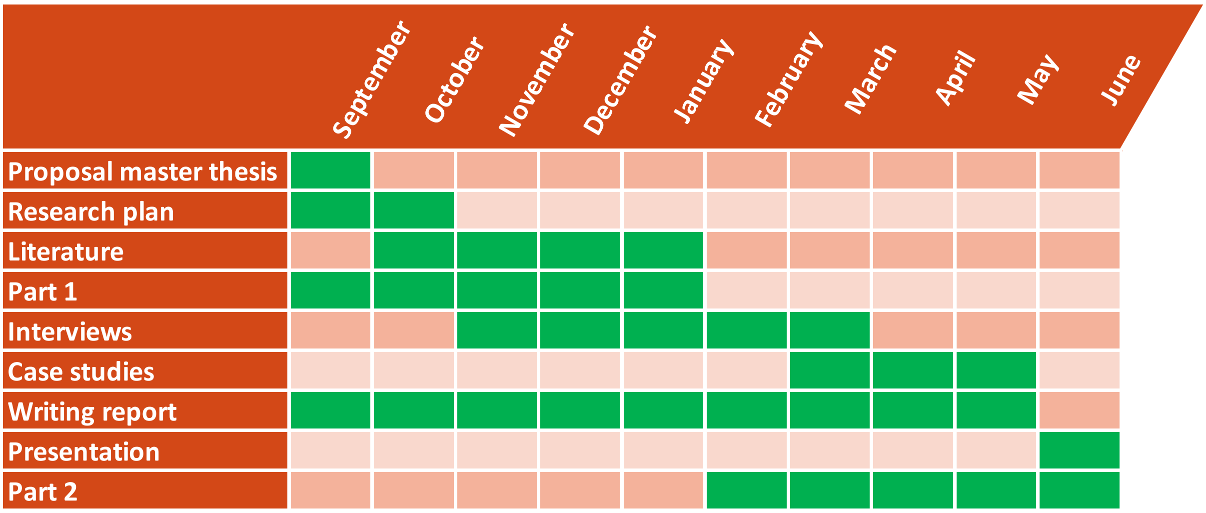
The collected data has to be analysed. Hereafter, the collection of the literature will be summarised and merged to a concise text which is written in chapter 2. In total 73 sources are investigated. There are interviews conducted with 11 different experts. The data collected from these interviews is partly merged with the other literature in chapter 2. Another part is written in the analysis of chapter 4. There is no data obtained from the traffic model Veins because it is not used in this investigation. Nevertheless, there is some data obtained from other sources. The studies made in chapter 4 are based on interviews and written documents.

3.3 Timing

The time schedule of this research is divided into monthly targets. The thesis started in September 2015 and is finished in June 2016. Table 1 contains the Gantt chart planning.

- September 2015, start of the research; approval of the proposed subject.
- October 2015, research plan making.
- November 2015, start of the literature investigation; interviews with stakeholders.
- December 2015, further literature investigation; expert interviews.
- January 2016, first part of the paper; presentation about this part.
- February 2016, improving comments of the first part.
- March 2016, analyses; case studies.
- April 2016, finish the analyses and case studies.
- May 2016, finishing the second part.
- June 2016, end of the thesis; preparation of the presentation; defending the thesis.

Table 1 Gantt chart planning for this report



4 Analyses

4.1 WI-FI-P versus 4G

WI-FI-P is a type of DSRC that arranges data transfer for ultra-low latency in support of V2X related functionalities. Currently there is no operational and complete set of standards for WI-FI-P. Another technical challenge is because of the fact that chipsets and relevant software that are currently used need further development to be able to handle a larger amount of messages.

This technique requires on-board units in the vehicle with installation costs of € 300-800 per unit. For the roadside units there is need for fiberglass infrastructure, this is expensive. This challenge can be overcome if the manufactures deploy the technique on a large scale. Car manufactures would like to cooperate with road authority and the traffic centre to make sure that public messages will be received immediately. Enterprises want to be technical independent from public infrastructure because of additional cost, complexity and implementation speed.

WI-FI-P will be made viable and future ready, therefore there will be more testing of this technique. Some companies see deployment after 2020 and not earlier because of the challenges. There is a big need of international standardization and testing to make it a success. Public bodies should invest in this before the technique can be procured as a standard service from a private entity (Beter Benutten, 2015).

4G/LTE/5G is another promising technique for V2X communication. It can use the current network and investments are only needed in hardware. It can be sold as a service for companies that use a telecommunication network already. Another advantage is that most current devices already support 4G and it can be rolled out quickly. Car manufactures equip already most of their new vehicles with an on board unit which can communicate with the cellular network.

There is some development needed to use 4G at maximum capability. From field test turned out that the capacity is adequate during peak hour. The latency in 4G is point to point below 1 second. This can become lower in the future but it is only used with higher level of automation.

Due to the already large customer base will the costs be manageable. Nevertheless, there is need of an agreement about the ownership and privacy of the transferred data. The usage of 4G is possible in the next two to three years if there is some financial assistance. The deployment of 4G will be rolled out national for data transfer. Further enhancement will require additional hardware. There is need of international standardisation and some testing from 2018 (Beter Benutten, 2015).

5G will be built as multi layered of existing technologies and deployed ones. This makes its structure easy and simple to deploy and operate. 5G can be offered with a similar cost as today's cost if the mobile companies can reduce the cost of today's level to 1/1000 per bit (Elleithy & Elmannai, 2014).

4.2 Case studies

In this part, some case studies are described. Most of the times there is an introduction to the subject in the literature investigation and a conceptual model per case study. In addition, several components are explained. Afterwards the communication between the components is explained and a Unified Modelling Language (UML) is given. This UML diagram is a model what described the origin, destination and timing of certain communication. At last some sensors are explained which are necessary in the model.

4.2.1 Enforcement

In part 2.5.3, there is spoken about the problems concerning enforcement. There is a conceptual model described how the police can check the vehicles. In Figure 13, there are several components of this system.

- Mobile phone, this phone is connected to the on board unit of the car. The phone is used as driving licence that the police knows who is driving. It will be use to lock the vehicle and for remote control.
- On board unit (OBU), an on board unit is a device which is the brain of the car. It will communicate to several components. In case of an accident, the police can read the data from that on board unit. It includes the electronic licence plate, insurance and annual maintenance check. This on board unit has a kill switch that can be activated if there are suspicious circumstances.
- Central database, this database handles the communication between external stakeholders and the vehicle. The owner of the central database could be the traffic centre or the car manufactures.
- Police database, this database is communicating with the central database. It receives information from the central database and it can check if the vehicles are correct.
- Emergency vehicles, these vehicles will communicate directly to the on board unit so that the vehicles tell them what to do.

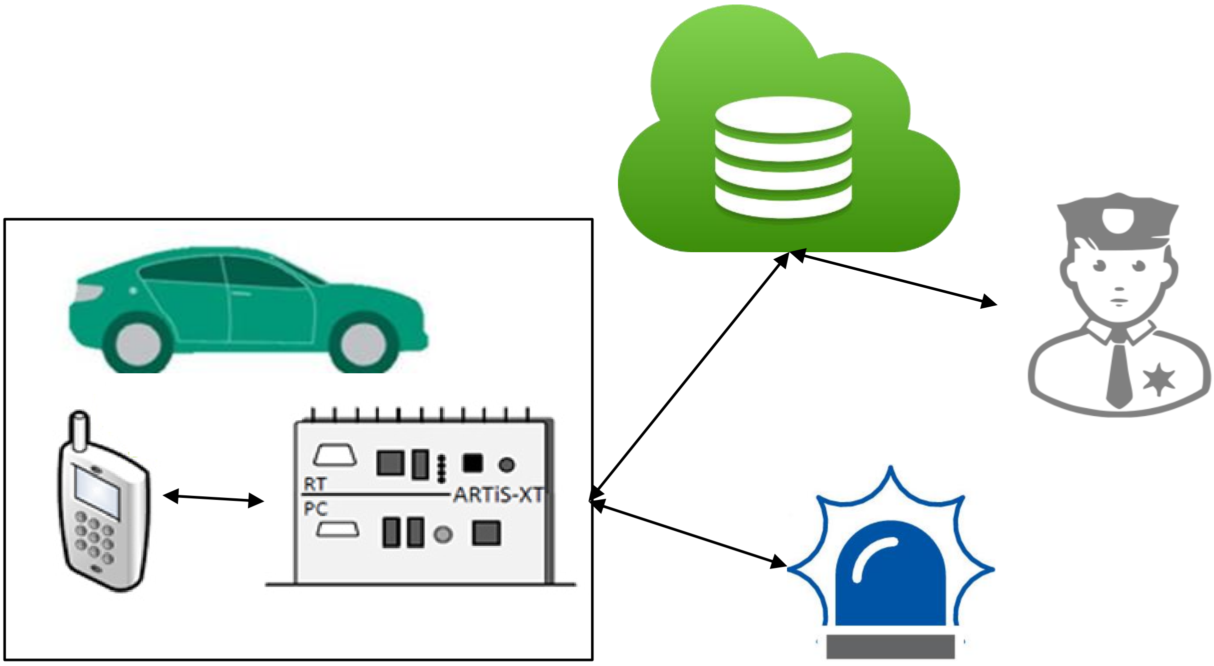


Figure 13 Conceptual model enforcement

Here is a listing about which information is send to which component (see Figure 14):

- Between mobile and OBU is information send about the driver licence and it can read on the phone what the condition is of the vehicle.
- Between OBU and central database is information send about the characteristics of the vehicle and the driver like insurance, annual check, valid driver licence, licence plate and normal characteristics that could be useful for the garage.
- Between the central database and the police database, only assets that are useful for the police are exchanged.
- Between the emergency service and the OBU, there only will be commands that the vehicle has to follow up.

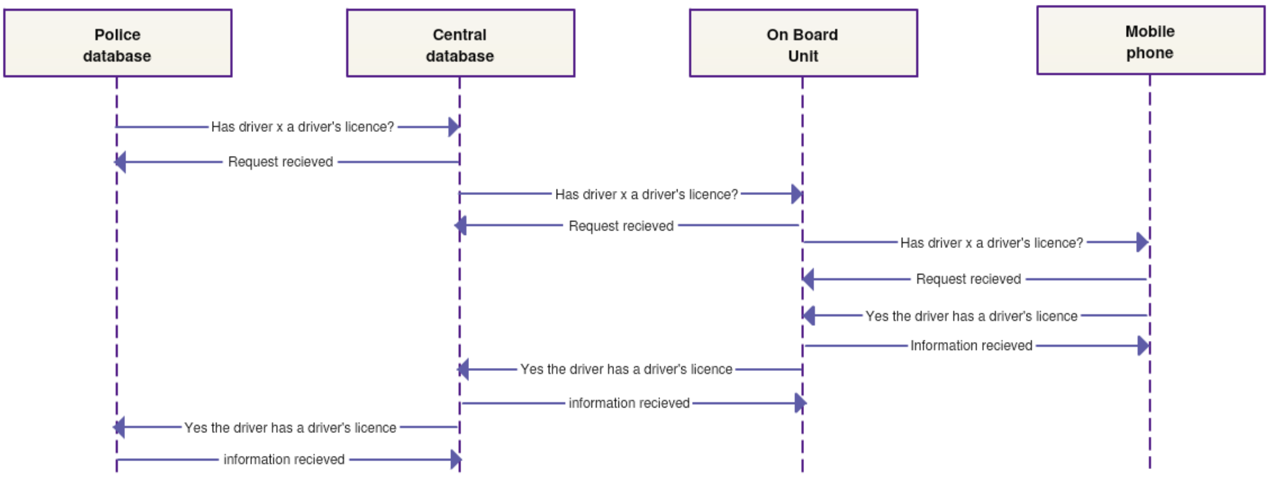


Figure 14 UML diagram enforcement

To get a feeling how many sensors the vehicle needs to have, they are listed below:

- Dedicated short-range communication (DSRC) between the emergency vehicle and the vehicle
- Between the phone and the OBU, DSRC can be used such as Bluetooth or WI-FI
- There is need for some sensors to monitor the performances of the vehicle
- For the communication between the database and the OBU, there is need for 5G communication.

4.2.2 Traffic signs database

The Flanders traffic sign database includes all roads in Flanders. On the map are all traffic signs drawn along any road, exactly at the place where they are located on the property. The Flemish government makes the database and it includes all municipalities in the Flemish Region. Since 2010, all signs are recorded in this database. All road signs and signposts throughout the Flemish Region, are listed in the database. In addition, all traffic lights and the official tourist signs are included. Each municipality in Flanders has free access to the database from that moment governments can track and manage the database for the territory of the municipality.

The road authorities that maintain the database over time can get many advantages. The database not only provides a more efficient functioning of the municipal services and cost savings. It contributes to important policy goals, such as increased safety, improved mobility and better quality of life. By integrating the database in GPS systems, the routes are managed better. It may possibly force the breakthrough of intelligent speed adaptation in cars, with a strong improvement in road safety as a result.

The online database can only work if the municipality keeps it up-to-date: all changes must be implemented. The best method to achieve this with minimum effort is to integrate the database with the traffic engineering as a working tool (Departement mobiliteit en openbare Werken, 2010).

In 2011, 2714 users are from local governments and police. In total, there are 4302 registered users. These come from 296 municipalities which means that many municipalities can see and adapt it (Departement mobiliteit en openbare Werken, 2011a, 2011b).

In 2013, there is a big update of the service. It is placed within Geoportaal Mobiliteit under Geoloket Verkeersborden. Therefore, the Flemish government can use it later with other sources. In 2015, around 130 municipalities out of 208 used it at least once. In Figure 15 there are the municipalities written. Yellow marked are municipalities which have seen the database, light green has done maximum 10 changes and dark green is more than 10 changes (Departement mobiliteit en openbare Werken, 2013).

The failure in updating the database is the main problem. There are several reasons, why the municipalities don't keep the database up-to-date. Firstly, there are no pressure measures to push the municipalities to update it. Secondly, the system had image problems at the beginning. Another current problem is more management related. The current manager is already more than a year ill and they do not know when he will be better. In addition, people who works there are still a bit old fashion. The other problems in the system are technical. The system does not check if someone fills in a false value. In the Vienna convention, only standards from visual signs are there no IT standards. In addition, the secondary signs are not regulated which should be easier for automated vehicles.

Figure 15 Municipalities used database (Departement mobiliteit en openbare Werken, 2013)

In 2015, the Vlaams instituut voor Mobiliteit (ViM) and the Flemish government have started a research how to use the information for ITS applications. Their research questions are; one application can be used for the automated vehicle. What will happen if all traffic signs are available in an intelligent way in the vehicle? How can this help the driver and improvement of the traffic flow? How can this database be updated on a dynamic way? There are some other concerns like about who is responsible.

ViM currently would update the whole map using the cameras of normal vehicles. When the map is up-to-date with all traffic signs, they need to be measured accurately. When this is finished, the vehicles can drive and read the signs. If there is a situation where the signs are different then there will be a signal on the map from a central database and the driver has to take over the control. This is level of automation 3.

When the system receives such a signal that there is a mistake somewhere on the road network, a team will go to that spot and they will update it. Ideally in a few hours the situation can be right again in the database (Vlaams instituut voor Mobiliteit, 2015).

There is a law that described that all EU member states should have a digital map available from their country. The traffic sign database is already a good start in this initiative (European Commission, 2011; European Parliament, 2010).

Below is a conceptual model explained that describes how the traffic sign database will be kept up to date. In Figure 16, there are several components of this system.

- Camera, the camera can read the traffic signs and compare it with the maps in the OBU.
- OBU, in the OBU there are digital maps downloaded which are constant updated by the database. If there is a mismatch seen by the camera between the maps in the database. A signal is send to the database that there is something wrong. In addition, a signal is send to the driver to take over the control of the vehicle.
- Driver, which receives a signal that there is something wrong with the map so the driver has to take over the control.
- Traffic sign database, in this database is the traffic sign map registered. If the database received a signal from a vehicle that the map is not correct it will send a signal to a measurement team.
- Measurement team, this team should go to the scene where a mistake is in the database. They should measure it.

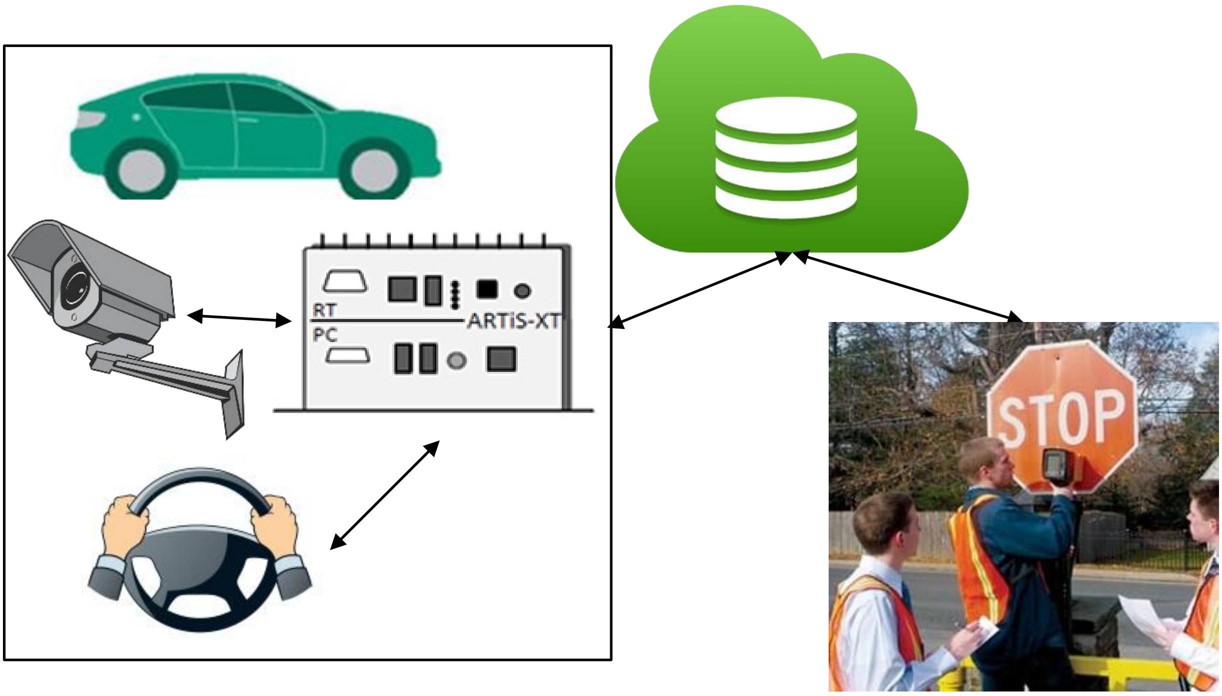


Figure 16 Conceptual model traffic signs

Here is a listing about which information is send to which component (see Figure 17Figure 24):

- Between camera and OBU is information send about the traffic signs that are seen by the camera. Traffic sign type, distance from car, images.
- Between OBU and driver is information send that he has to take over the control over the vehicle.
- Between OBU and database is information send about which signs are seen where. In addition is information send if there is a mistake. Traffic sign type, GPS-location, timestamp, distance from car, images and weather.
- Between database and measurement crew, information is send where the situation is not correct. Information like traffic sign type, GPS-location, images. In addition, if they have measured it, they will send this information to the database. This contains the right GPS-location, images and type of traffic sign.

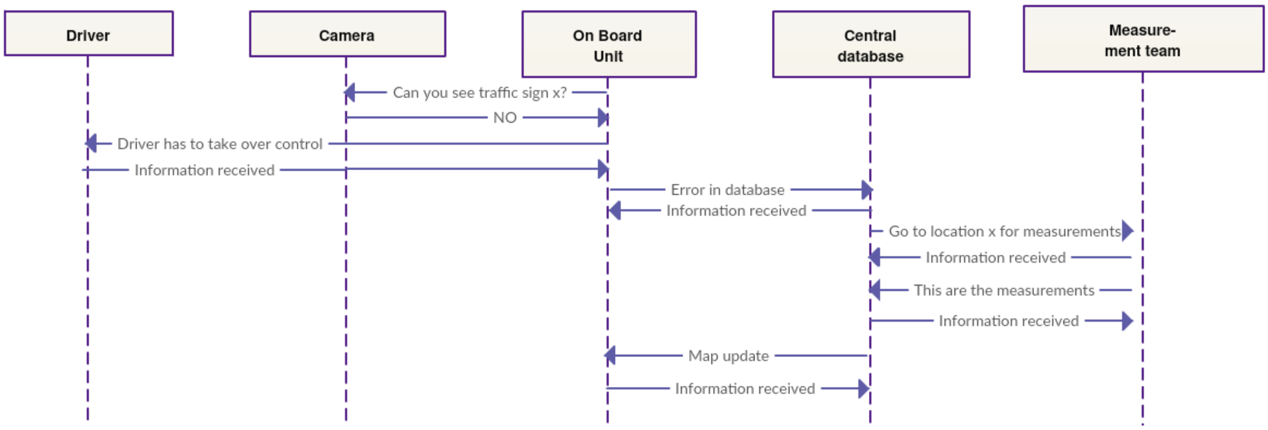


Figure 17 UML diagram traffic signs

To get a feeling how many sensors the vehicle needs to have, they are listed below:

- Traffic sign recognition camera to see all the signs and compare them
- A sensor that give the driver the signal that he has to take over the control
- Wireless communication sensors with the database, probably with 5G

4.2.3 Intersection

There are quite a lot studies about intersection controls for automated vehicles, but hardly in the transition period where not all vehicles are automated. There are three approaches for controlling the intersection which are investigated with all vehicles full automated called Cooperative Vehicle Actuator System (CVAS), Transparent Intersection Management (TIM) and deadlock-free policy. CVAS and TIM concern a single intersection whereas the latter tackle the problem of deadlock into a network of intersections by using either CVAS or TIM. For the three proposed approaches, vehicles cross the intersection by negotiating with other vehicles through a server. They have a kind of “personalized” right-of-way. In an ideal case, there are no traffic lights.

The traffic is optimized by deciding which vehicle or a group of vehicles crosses the intersection first, which one is the second etc. In CVAS, the right of way is a semaphore that informs whether the vehicle is allowed to cross the intersection. TIM is different; there is no exactly a right-of-way. Instead, vehicles synchronize their speed according to real and virtual obstacles. This is possible only with automated vehicles. The most important results are written below.

CVAS compared to traffic lights: It is important to have a good policy to optimize the traffic. With Distributing Clearing Policy (DCP), they gain more than 40% of stop time, travel time and evacuation time in the case of a high traffic intensity. When the traffic is low, they avoid useless stops. In all cases, DCP is near to the optimal solution.

TIM is better than CVAS if the communication time is small (less than 500 milliseconds to get data of all precedent vehicles). They have more than 20% of improvement of stop time, travel time and evacuation time. Otherwise, TIM can behave as CVAS and even worse if the communication time is big (more than two seconds to get data of all precedent vehicles).

In a network of intersection: It is hard to evaluate the deadlock free policy because there is no well-known deadlock free simulator. However, humans in general avoid deadlock by moving back, by communicating with others letting them passing before, by tightening the queue and by changing their itinerary if it is required. Automated vehicles are not smart enough. Hence, there is a need for deadlock-free algorithms if there are many automated vehicles in the city. The algorithm is deadlock-free. They compared it with an optimized traffic light in VISSIM, for a grid of 25 intersections. There are 20 meters between each intersection in order to rise the chance to have deadlock. If all vehicles go straight, there is no deadlock in VISSIM and the traffic behaves almost as the policy. When 10% of vehicles turning left and 10% of vehicles turning right, the policy allows to have 62% (about 2400 vehicles per hour) of additional vehicles in the network of 25 intersections in 0,04 km^2.

The traffic centre can play a role in these network of intersections to make sure that there is no deadlock. It also can manage the traffic flow and give more priority for a specific direction. This also could be depending on the policy from governments where different vehicles are going to travel.

These results are based on the protocol. The results of AIM based on the reservation are more optimistic. However, from their point of view, the protocol is feasible (Abbas-Turki & Galland, 2016).

Currently there are also tests going on about other intersection protocols without a central server in the Grand Cooperative Driving Challenge (GCDC). It is an innovative and competitive demo event on the A270 highway between Helmond and Eindhoven, in which 10-12 European teams compete with each other. The challenge is a combination of vehicle automation (making it self-driving) and V2V and V2I communication. The GCDC 2016 is organized to provide a basis for cooperative automated driving in an international context. The results of the i-GAME research project will be made available to the teams so that they can be demonstrated, according to three scenarios:

1. Merging vehicles or joining a line of vehicles, known as platoons.
2. Automated crossing and exiting a junction.
3. Automated space-making for emergency vehicles in a traffic jam.

Apart from the communication technology itself, it is the application in the vehicles that is key to enabling good maneuverability through automated acceleration, braking and steering. This edition, judging will be based on: teamwork, mutual communication and the results of each team in the different traffic scenarios (see Figure 18). (GCDC, 2016)

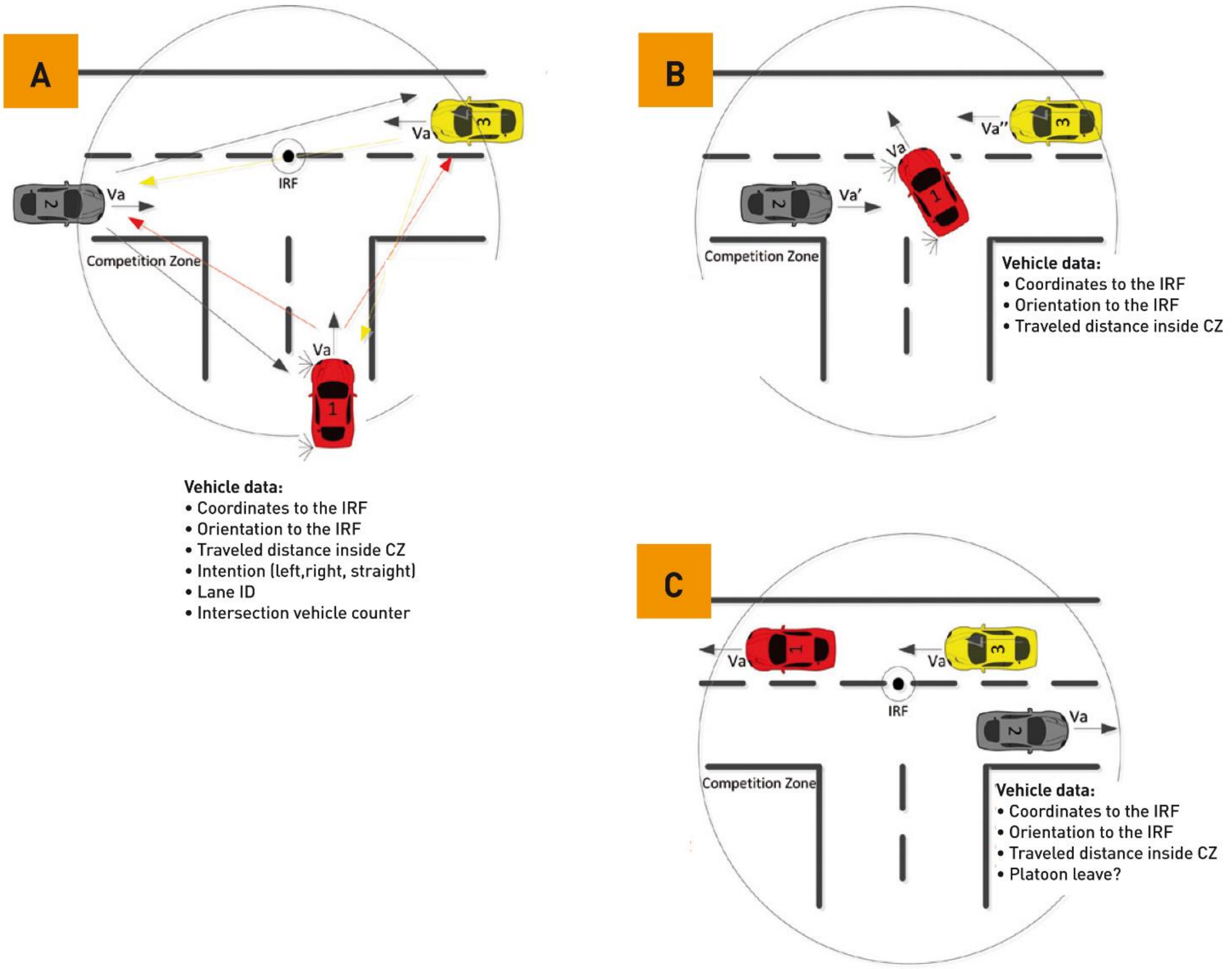


Figure 18 Intersection GCDC (GCDC, 2016)

Below is a conceptual model explained that describes how the traffic light will work in the future. Two vehicles want to cross the intersection. In Figure 19, there are several components of this system.

- Vehicle 1 wants to go straight at the intersection
- Vehicle 2 wants to go left at the intersection
- Server it will control the intersection

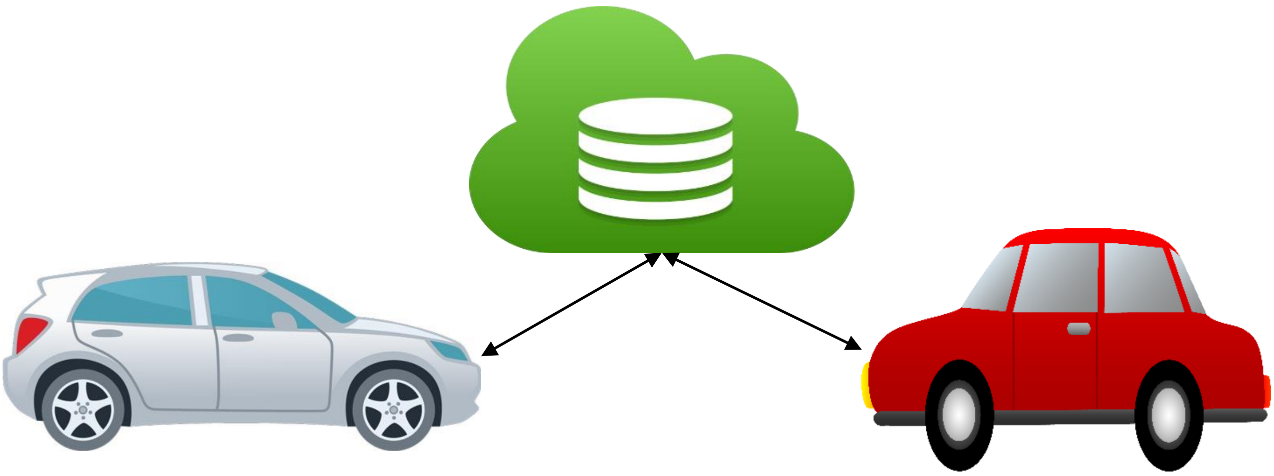


Figure 19 Conceptual model traffic light interesection

The communication between the several components is described here (see Figure 20):

- Vehicle 1 to server requests to cross the intersection. There is no other vehicle so the request is confirmed.
- Vehicle 2 to server requests to cross the intersection. There already is a vehicle so the request is not confirmed. The vehicle will slow down and try to do it a second later.

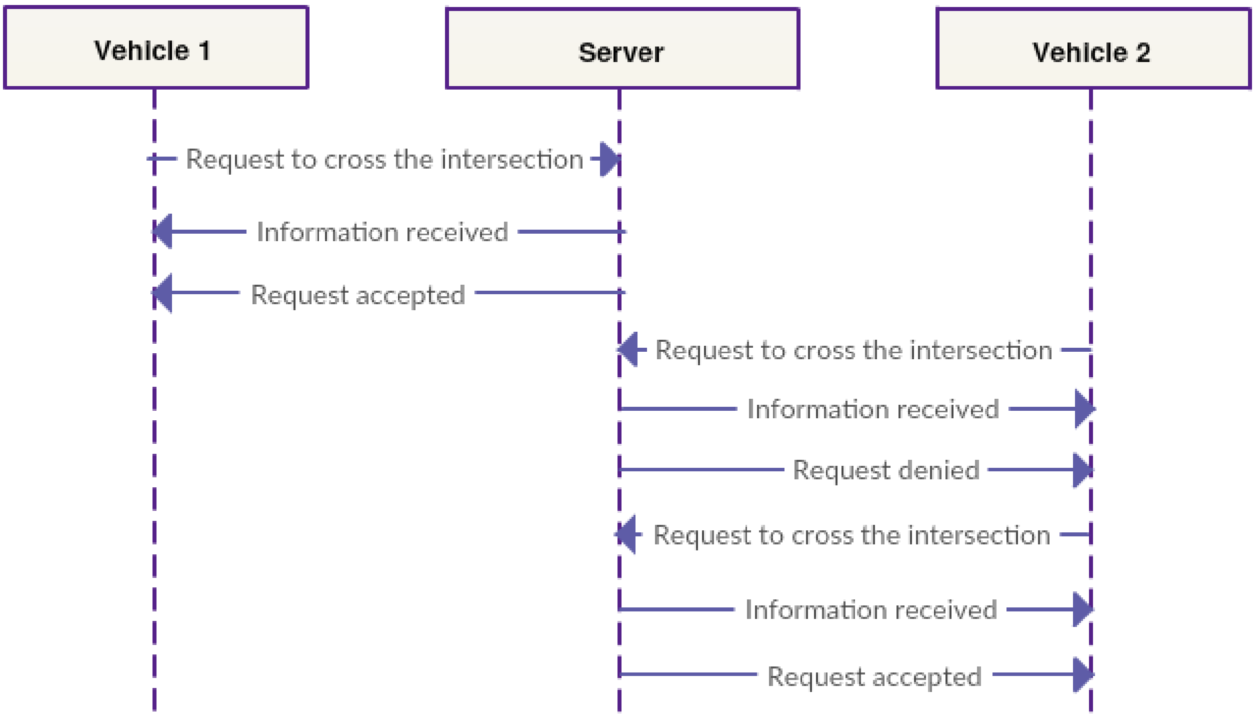


Figure 20 UML diagram intersection

The sensors that are needed to operate this intersection crossing are listed below:

- Dedicated short range communication with the server
- GPS sensor of the current location
- Speed sensor to estimate the arrival time at the intersection

4.2.4 Infrastructure asset management

Infrastructure assets relatively have long expected services. The operational and financial management are viewed primarily in the long term. Postponement of needed maintenance or funding to sustain these assets are common occurrences, especially under the treats of tight budgets and political pressure for spending on more visible things. Asset management means knowing which infrastructures they own, what kind of condition it is and what the financial burden will be to maintain it at a targeted condition (Cagle, 2003).

The automated vehicle will drastically change the asset management of infrastructure. On the one hand because these vehicles need other kinds of infrastructure, on the other hand because the vehicles will have sensors that can tell something about the condition of the infrastructure.

An essential implication for an automated vehicle infrastructure is that traffic capacity will increase exponentially without building additional lanes or roadways. Research indicates that platooning could increase highway lane capacity by up to 500 percent. It may even be possible to convert existing vehicle infrastructure to bicycle or pedestrian uses. Automated transportation infrastructure could bring an end to the congested streets and extra-wide highways of large urban areas.

The convergence of sensor-based safety systems and connected vehicle technology could assist transportation agencies with asset management and reduce maintenance costs. Vehicles could report road or weather conditions back to transportation agencies, which could then rapidly address issues such as road deterioration. If necessary, automated vehicle traffic could automatically be rerouted around problem areas while maintenance crews address the problem (KPMG & CAR, 2012). NXP is currently doing tests with these kinds of applications (Geraets, 2012).

In this system there will be described how automated vehicles will give information of the conditions of the infrastructure. In Figure 21, there are several components of this system.

- Vibration sensors, which give information about the amount of vibration during driving to the OBU.
- Camera can give a picture about the state of the roads.
- Road authority database will receive all this information and will determine what to do with it.
- OBU that receives the information from the traffic centre what to do.

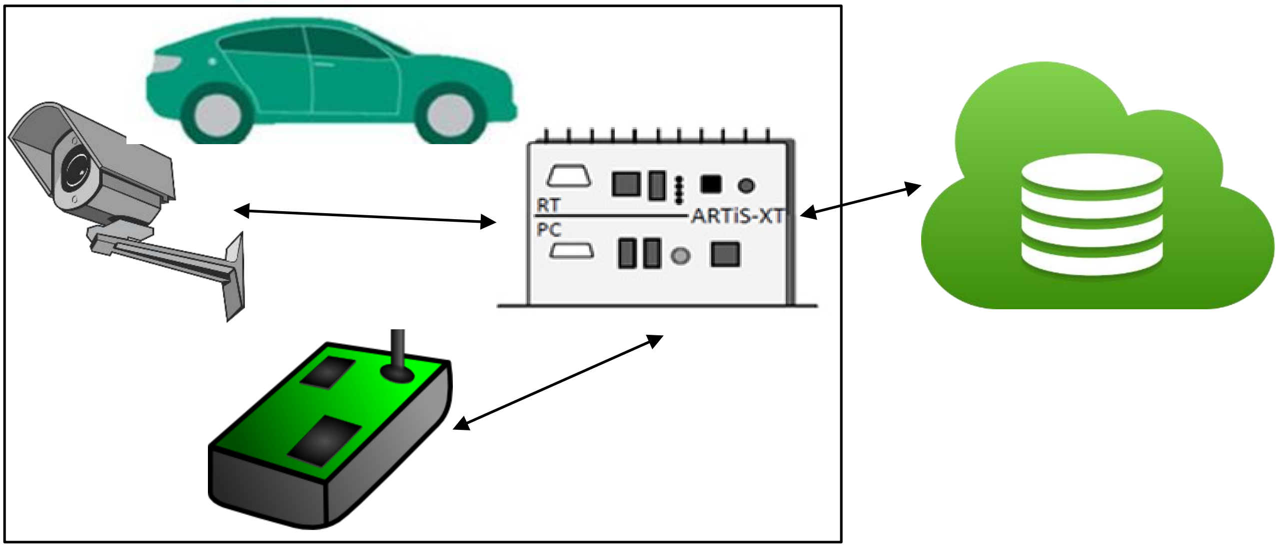


Figure 21 Conceptual model infrastructure asset managenent

The communication between several components is described below (see Figure 22):

- The OBU askes to the vibration sensor and camera what the status is of the road at a particular moment. The sensor and camera will send the information to the OBU.
- The OBU gives information about the road condition to the road authority. If the authority is curious about a road condition, it can ask an OBU to give information when it is driving there.

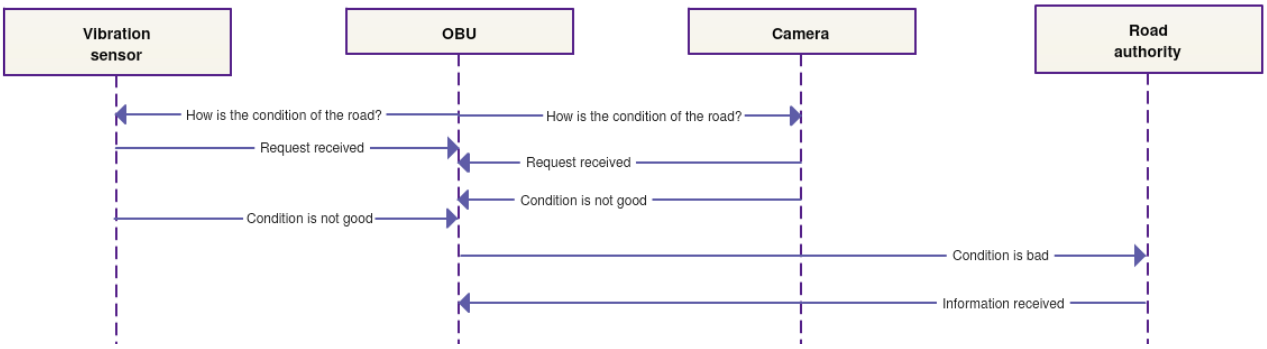


Figure 22 UML diagram infrastructure asset management

Following, the needed sensors:

- Vibration sensor to measure if there is a lot of vibrations going on at a particular road segment
- GPS for precise location
- Communication sensor with the road authority
- Camera to make pictures

4.2.5 Road works

The traffic centre will be in charge of all dynamic information. In this part there will be made a conceptual model that describes how the information flow during road works will be functioning in the future. In Figure 23, there are several components of this system.

- Traffic centre has the control over all unexpected road conditions like road works
- Maintenance crew will do the road works on the site
- OBU which receive the information from the traffic centre what to do

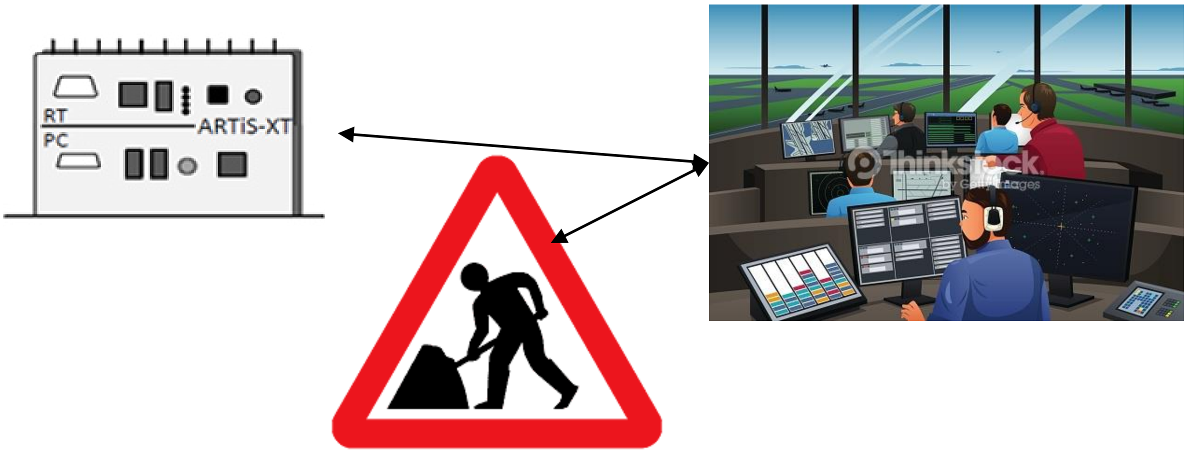


Figure 23 Conceptual model road works

The communication between the components is below-mentioned (see Figure 24):

- Maintenance crew to traffic centre gives information that they start working
- Traffic centre to OBU gives information about the road works and about what to do. For example, lower the speed or go to another lane.

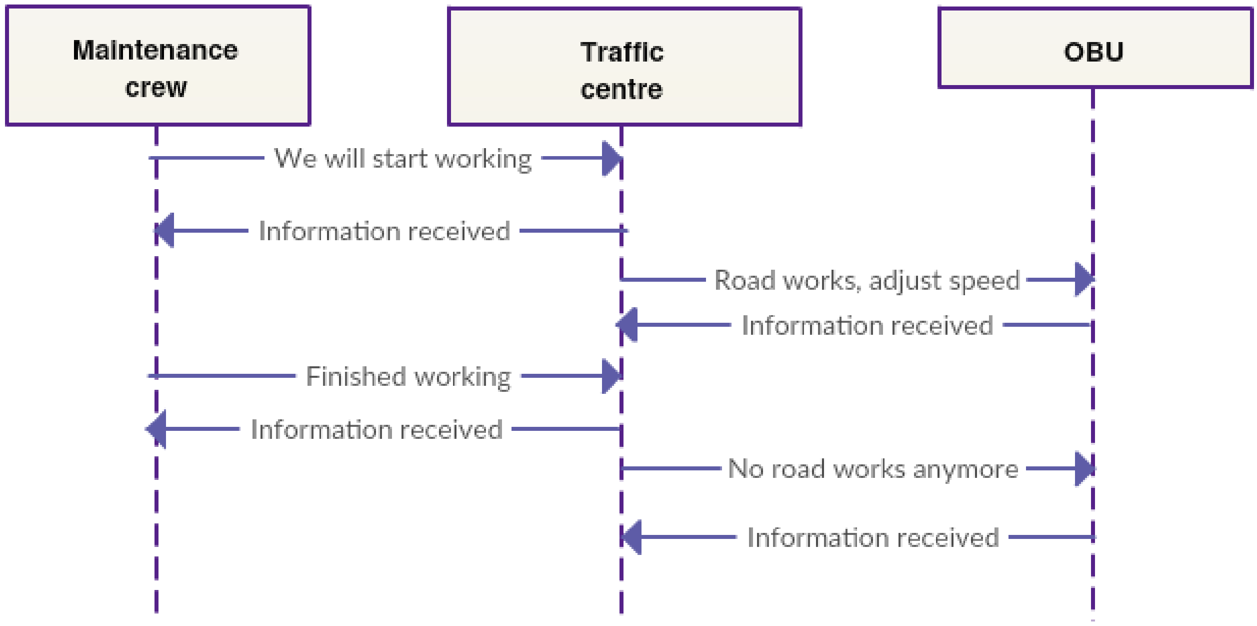


Figure 24 UML diagram road works

The sensors that are needed for this situation are listed here:

- Sensor for communication
- GPS for precise location

4.3 Declaration of Amsterdam

Mobility will change more in the next twenty years than in the past one hundred years. Besides technological progress, there are further challenges and uncertainties related to development of connected and automated vehicles. There are important questions to be answered regarding security, social inclusion, use of data, privacy, liability, ethics, public support and the co-existence of connected and automated vehicles with manually controlled vehicles (The Netherlands EU Presidency, 2016).

EU support the development of automated driving through a range of initiatives. Automated vehicles are already being tested on public roads and are gradually being introduced on the market for commercial use. In the early stages of this transition, open competition between different models and initiatives is needed to instigate creativity and innovation. However, both industry and users demand that new services and systems should be interoperable and compatible when crossing borders. The European Commission has taken important steps with the Cooperative Intelligent Transport Systems platform, the Round Table on Connected and Automated Driving and the Gear 2030 initiative. Nevertheless, a more coordinated approach is called for countries and at European level to remove barriers and to promote a systematic learning-by-experience approach. It is essential to support an exchange of information of results and best practices by linking and integrating initiatives (The Netherlands EU Presidency, 2016).

In the declaration of Amsterdam, countries said to have acknowledging that automated vehicle technologies offer a great potential. Recognising the long-term potential and the challenges and uncertainties related to the development of connected and automated vehicles. The important initiatives support innovation in the field of connected and automated driving. Make the position of Europe better in the field of automated driving. Recognise the benefit of a more coordinated approach towards the development of connected and automated driving. Recognising the need for a systemic approach to ensure that benefits for the transport system as a whole and to support seamless door-to-door transport as well as value-added services using data generated by connected and automated vehicles while at the same time ensuring data protection (The Netherlands EU Presidency, 2016).

They agreed on shared objectives and a joined agenda. The countries, European commission and the industry will all take actions to support the development of the automated vehicle (The Netherlands EU Presidency, 2016).

It is important that there is an effort to harmonise the policy plans in Europe. Vehicle manufactures can easier make a vehicle ready for Europe instead of making it different for all countries. In addition, it will be easier for the driver cross borders.

5 Conclusions and recommendations

This research started with the main question; “how can the current investments in the road network be made sustainable for the introduction of automated vehicles?”. This broad question is split up into three sub questions. The first question is about how automated vehicles can get static and dynamic information. The second sub question is what the future of the traffic signs will be. The last sub question is what the role of the government in function of the automated vehicles will be. First, there is a literature investigation done and in the analyses there are some case studies written.

The first case study is about enforcement. The police still need a kind of enforcement and traffic management on the scene. The clarification of fundamentals, such as insurance, driver licence, licence plate and annual check. These things will be done on distance, however, all other enforcement will happen at the scene. The communication from the police to the driver will go through a central database to the OBU. It is essential for the police to invest in WI-FI-P equipment to communicate with automated vehicles.

The second case is the Flemish traffic sign database. It is a database set up by the Flemish government to have an overview about where all traffic signs are. It is a useful tool for automated driving, although the database is not maintained well. Although there is research going on to improve this data and use it for automated vehicles. To keep the database up-to-date, it is good that there is a rapid response team, which can intervene if a traffic sign is detected at another place as in the database. In the short term most of the traffic signs will stay and at the long term they mainly will disappear.

Intersections probably will change dramatically. There are several protocols to make an intersection more efficient without lights. However, there will be need for a small server at each intersection to receive the signals from the vehicles.

The fourth case is about infrastructure asset management. The asset management will change dramatically. This means that the policy can be adapted. Governments get information quicker, they can adapt their policy to maintain the road. It is important that governments are responsive against this change.

The last case is about road works. First, the asset management is done and if governments say there is need for road works, this case will play a role. The road workers will talk to the traffic management centre when they start working and for how long. The traffic centre can than send this information to all vehicles so that they know what to do. There is still a role for the traffic centre then will slightly change because it will communicate via 4G directly to the vehicles.

Lately the member states of the EU have agreed on the declaration of Amsterdam. This will increase a uniform policy in Europe, which is good for the implementation of the automated vehicle.

To have a good recommendation towards different policy makers it is important to follow the next steps in policy making. The first step is to recognise what an automated vehicle is and what the benefits are. The second step is to do many tests in closed circuit and on the road. The third step is to make law about the implementation of automated vehicles. And the last step to make policy about how to implement automated vehicles.

To conclude this report and write about the investments which are necessary or not. According this investigation, it is important to invest in a central database where different stakeholders can tap in for different purposes. If this “traffic centre” is owned by the government, an external party or car manufactures is not known. The different governments should invest in the connection to this database and the different applications they want to provide. It also is important to invest in in-car systems used by WI-FI-P and 5G standards. It is less useful to invest in roadside systems, except for systems to capture the communication. What the physical infrastructure requirements are in the future is not known.

6 Future work

In this report there are some gaps, which can be answered in a next research. The first major gap is that there has not been any modelling, due to the limited time available and the focus of expert interviews. Nevertheless, the case studies are extensive written above, now the main part should be focussing on making the model and analysing it.

A second point is that there currently is not enough consistence between road authorities. There is a need for more guidelines. Even in Belgium the regions are in charge of implementation of automated vehicles (Soens, 2016). However, there are efforts to harmonise the policy in Europe though the declaration of Amsterdam (The Netherlands EU Presidency, 2016).

In the viewpoint of car manufactures, it does not matter if a vehicle is automated or not. They only want to sell cars and they focus on environmental or safety reasons. Another market where they want to grow are elderly and disabled people. Automated vehicles are a solution to all of these reasons. However, there has to be a balance between supply and demand, as car manufacturers are interested in profitmaking.

Another remark is that some persons say that governments are out-of-date. With the implementation of the internet many things went wrong and/or slowly. If this technology is emerging, the question will arise if governments are ready for this change and if they have enough knowledge to enact laws and policies.

In the literature it not always was clear about which level of automation a specific research or application was about. This makes it hard to compare different studies. It would be good if researchers indicate in the introduction about which level of automation they are researching about.

Another drawback of this report is the lack of literature about automated vehicles. Most of the literatures are policy plans. This is because it is not known which technology will be used by the manufactures and there are no governments, which say this technology has to be in a vehicle.

The last weakness is that the voices of experts are not scientific. These are only opinions from experts and not always scientific proven.

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