Social desirability and mobility impacts of early forms of automated vehicles

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Societal and transportation impacts of early forms of automated vehicles in the Netherlands

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A summary in Dutch can be found at the last page of the report

Preface

This thesis is the graduation work for two degrees at the TU Delft: Transportation & Planning and Science Communication. Both courses deal with automated vehicles, or to be more specific: the impacts that automated vehicles have on society. For the transportation part (part A) the mobility impacts of early forms of automated vehicles are researched. In the communication part (part B) a method is developed to involve the public in the automated vehicle innovation.

This thesis is made with the help of several people. To start, I would like to thank my committee for their input during my master thesis. Where in the Bachelor Civil Engineering you barely receive personal feedback (only in the form of a grade for an exam), I experienced the opposite during this master thesis. During the kick-off, mid-terms and green light and intermediate meetings I got much feedback from all supervisors.

First, I want to thank Bart van Arem for enthusing me for self-driving cars, the useful contacts in the field and the feedback I received. You opened many doors for me. Next, I want to thank Rob van Nes for bringing up the method of System Dynamics and all the discussions on the model. Especially the all the side tracks on modelling were interesting. Els van Daalen, I did not expect to receive this much feedback from my external supervisor. Between the first and second time I visited were 5 months but within no-time you remembered precisely what I was doing. Maaike Snelder, thanks for giving me the opportunity at to do my graduation at TNO and the feedback you gave.

Furthermore, I want to express gratitude to my supervisors from Science Communication. Steven Flipse, thanks for the feedback and guidance. I like your strong vision and bold way of expressing yourself. Caroline Wehrmann, thanks for the feedback on the scientific field.

To all supervisors goes appreciation for the time I had to cope with RSI, I received many kind e-mails. I didn't feel any pressure to start too early.

Next to my supervisors, a lot of other people helped me with the thesis. Many thanks to the people who helped me with testing or performing the workshops, the interviews, the questionnaires, making the movie. Special thanks to the ones who gave feedback on the report and Kees van Goeverden for helping me with struggling with the OViN data. I also appreciate the help I got within TNO from the other students and colleagues for giving me information, feedback and fun during work.

Besides the study related credits, I want to express my gratefulness for time in Delft. Not only at the TU, but also outside the TU I learned a lot, had a great time and made many friends. Luux, Bamb, Oele, Abra, Bestuur, roommates, study friends, Noortje, and many others, thanks for the fun, I hope more is coming. Lastly, thanks to my parents who made it possible that I could do my study without boundaries and could do what I liked. I experienced a lot of freedom.

Steven Puylaert
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Summary

Introduction for both part A and B
The first forms of automated vehicles (level 1 and 2) are already available at dealers, and next levels are being developed at this moment (level 3 and up). Literature indicates two development paths for automated vehicles: an autonomous and a cooperative path. Autonomous vehicles only monitor the driving environment, whereas cooperative vehicles also communicate with other vehicles or roadside systems. This thesis consists of two parts: one (part A) researching the mobility impact of these two development paths, the second (part B) develops a method to include the public in decision making around automated vehicles.

Part A: Modelling the mobility impacts of automated vehicles
Governments are eager to know the impacts that automated vehicles have on mobility. Investment plans and policies can be made with this information. Current macroscopic models that assess the large-scale impacts of automated vehicles are complex, unsuitable for explorations with many uncertainties and are not able to simulate multiple vehicle types. This thesis aims to explore the impacts of early forms of automated vehicles (level 1, 2 and 3) on mobility.

To cope with this problem a System Dynamics model (SD-model) is built. This model is based on the structure of the ScenarioExplorer, a model developed by TNO in the 1990s. The SD-model is strongly explorative and does not make use of an explicit road network. The goal of this model is to capture the most important effects of automated vehicles, but not to go into all the details. As the structure is simple and the run time is short, the model can be used to assess different scenarios.

> In this study a System Dynamics modelling approach is chosen to model the mobility effects of early forms of automated vehicles on mobility in the Netherlands (2013 until 2050).

In this model the road capacity, value of time and fuel economy effects of automated vehicles are researched. The different levels of automated vehicles are modelled as different user classes in the mode choice, time of day choice and the assignment. This is novel for modelling automated vehicles on a large scale. In the assignment PCU factors depended on the penetration rate are used per vehicle automation class. This PCU makes it possible to translate results of microsimulations easily to large scale models and to simulate mixed traffic.

The SD-model is compared to three macroscopic models and historic data and shows similar results. In addition, other tests point out that the model is suitable for explorative studies.

Simulations with the SD-model show that due to the benefits automated vehicles bring, they will lead to extra car traffic in all researched scenarios. In the cooperative development path, the travel times on characteristic relations will roughly stay the same due to capacity benefits. In the autonomous development path, the average speeds drop due to less capacity benefits. The model shows that early forms of automated vehicles will not reduce congestion and in most scenarios have a negative effect on mobility. The only benefits early forms of automated vehicles entail are for the drivers, but not for mobility as a whole. Governments should therefore invest in other measures to stimulate the mobility. Due to the increase in car traffic, more emissions are expected.

Part B: A more responsible innovation through the use of a constructive dialogue

Societal impacts of automated vehicles can be large, not only on mobility, but also on safety, privacy or security. Complicating aspect is that automated vehicles both influence the living environment of the consumers and other road users. Literature indicates that at this moment the public (both user and other road users) are important stakeholders, but are not enough involved in the automated vehicle innovation. Due to this, and other flaws, the automated vehicle innovation cannot be called a responsible innovation. not involving the public constitutes the risk of neglecting their fundamental ethical principles, as their opinions remain unheard.

This research aims to develop a method to involve important actors and to translate their ethical principles into starting points for a design of future automated vehicles. The values of four important actor groups (the government, manufacturers, consumers and non-consumers) are investigated. The method aims to be a constructive dialogue method.

This study investigates the values of different actors and a constructive dialogue approach to base the design of automated vehicles upon values of all actors.

The value profiles created from the questionnaire show that opinions of the various actors differ. All actors agree that *safety* is the most important value. Differences are that the government and non-consumer value *traffic flow,* whereas the car manufacturers value *spending time differently* and *self-determination* for the driver. The cooperative path therefore seems attractive for the government and the non-users, whereas the car manufacturers are most likely to be in favour of the autonomous path. The survey shows no preference for one of the two paths from the consumer.

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To create a common value profile a dialogue is needed, this is done in workshops. Tests with the constructive dialogue workshops show promising results: tensions in values become clear and the students reach consensus in the workshop. This is empirical evidence for what Van de Poel (2013) describes in his paper on specifying values to design requirements. The set-up seems to be a way to involve the different actors. This method is therefore a step towards a more responsible innovation for automated vehicles. Another promising aspect of the method is that the new ideas which are not mentioned in literature on self-driving cars arise in the sessions.

This research contributes to a more responsible innovation as stakeholders are involved. Still, other important steps have to be taken. The method which is developed in this thesis should be used by manufacturers to give input to future designs or by governments for policies. Future research should focus on the validation of the workshops and the embedding of the method.

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1 Introduction

1.1. Automated vehicles will soon be part of our society

The long envisioned automated vehicle is coming closer and closer to our daily lives. The first versions of automated driving are already commercially available and more advanced versions are being developed. Changing the human driver for a computer is expected to have benefits. The most mentioned effects are less congestion, a safer way of traveling and a higher energy efficiency (Milakis, van Arem, et al. 2015; KPMG 2012; Litman 2014; Snelder et al. 2015). Not only the way we move ourselves can change, the automated car can also have effect on wider societal issues, such as privacy, equality or social exclusion (Fagnant & Kockelman 2015). These can be positive, but also negative (Litman 2014, p.4).

How will this technology change our society?
Large amounts of money have been invested in automated vehicles (Timmer & Kool 2014), but the potential benefits are also large, both in terms of profits for companies and nationwide welfare (Schultz van Haegen 2014; Anderson et al. 2014). As the development of automated vehicles is a complex technical, economic and multi-actor political process, the outcomes are uncertain (Timmer & Kool 2014). Governments and other planners want to get a grip on these uncertainties. Nevertheless, getting a grip is hard: when a technology is widely available, the structure is hard to change, but if technology is not available, the impact it has is hard to foresee. This dilemma is called the Collingridge Dilemma (Collingridge 1980) and plays a tricky but challenging role in every forecast on innovations.

Assessment of technology (van de Poel & Royakkers 2011, p.78) can help to overcome this dilemma. This research aims to investigate two aspects of the automated vehicle innovation:

  A. the effects automated vehicles have on mobility, and
  B. the social desirability of different development paths of automated vehicles

Reading guide: two studies in one thesis
These two topics, the social desirability and the transportation effects, are presented separately in this thesis. The core of both studies is presented in the *transportation part (A)* and the *communication part (B)*. The outcomes of the two studies are again combined in one essay which integrates both studies.

figure 1-1: The research starts with a common introduction for both topics. 1.2 shows the problem for transportation, 1.3 the research question and goal for transportation (part A). For communication the problem is shown in 1.4, the research question and goal in section 1.5 (part B). After the introduction the core of both researches is presented. The report finishes with an essay which integrates both topics.

Firstly, information will be given about automated driving and different development paths. Secondly, an explanation is given why transportation effects are hard to forecast, followed by a problem sketch of social desirability. At the end of this introductory part the goals and research questions of the two studies are posed.

Levels of automated driving: there are many different types of self-driving cars

Automated vehicles are not one single product. The self-driving car does not exist, or better: there are many different types and flavours of automated vehicles. Automated vehicles can be seen as a scale from letting the driver do all the driving, to full automation where the computer does all the driving (SAE International 2014). The road safety authority NHTSA in the US created the 6 step SAE-scale; which has become the standard for most research. Some products, which can be seen as a first step for automated cars, are already commercially available, for instance adaptive cruise control or lane keeping assistance. They are called level 1 vehicles, whereas the fully automated vehicles without steering wheel are called level 5 vehicles. A full overview of the levels is shown in figure 1-2.

In 5 levels from manual to automated driving
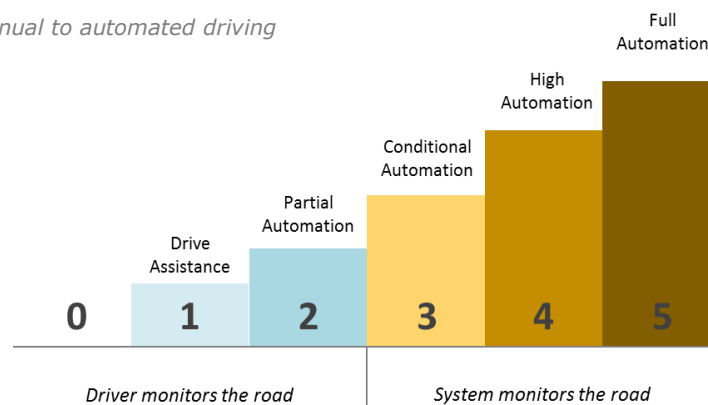
figure 1-2: From manual to automated driving in five steps (figure based upon SAE International 2014).
Some examples per level: Level **1**: adaptive cruise control. Level **2**: adaptive cruise control and lane keeping. Level **3**: able to read a paper, but driver needs to take over the wheel when asked. Level **4**: Car can get itself into safety if it isn't able to handle a difficult driving situation. Level **5:** No steering wheel needed anymore, automated driving under all conditions.

Two development paths for self-driving cars

Over time the vehicles on the road will gradually become less manually steered and more automated. Literature indicates two development paths for the future: *autonomous driving* and *cooperative driving* (Timmer & Kool 2014; Wilmink et al. 2014; Bhat 2014; Milakis, van Arem, et al. 2015). Which all have different drivers behind the developments (Aerts 2015).

The first of the two extremes is *autonomous driving*. In this development path the car drives on its own, and only 'looks' (monitors) at the world outside. An example is the Google car (Google 2015b). The second extreme is the *cooperative* path. Cooperative cars monitor the driving environment and communicate with other vehicles and infrastructure. These cooperative cars can drive in groups or trains. Examples are the DAVI or the SARTRE-project (Hoogendoorn et al. 2013; Volvo Trucks 2012). The autonomous path can be seen as the basis and the cooperative as an extension of it. This cooperative extension however, can be added at the end, or also in all steps in-between. An example of a low automation level with communication is for instance cooperative adaptive cruise control instead (CACC), instead of adaptive cruise control (ACC).

Thus, the autonomous path argues for making the cars drive on their own first, whereas the cooperative path argues for directly making the vehicles communicate with each other while they are automated. Figure 1-3 shows this graphically. Table 1-1 shows the differences in the two paths.

The 2 development paths: cooperative and autonomous
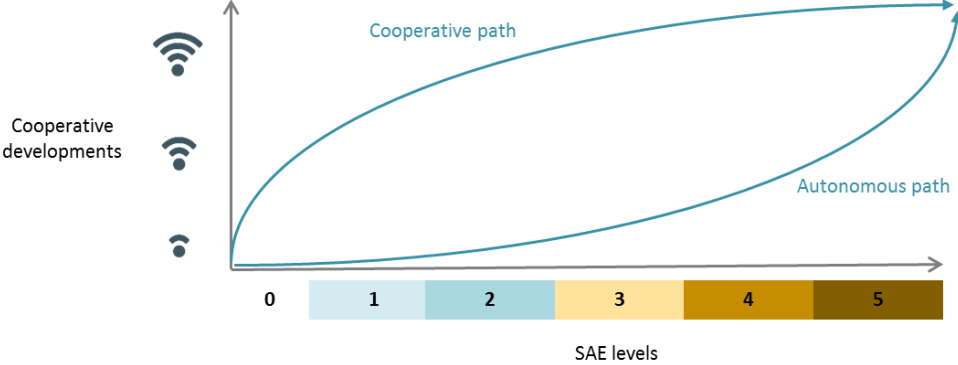
Figure 1-3: Autonomous developments ensure less involvement of the driver and more steering driving task are being taken over by a computer. The cooperative developments ensure the vehicles communicate with each other. The blue lines indicate the two development paths: cooperative driving and autonomous driving.

The two development paths make forecasting hard, a scenario analysis suits better
Due to this difference in paths it is hard to make one forecast for the future. To overcome these uncertainties, a scenario analysis[1] can be done. A scenario analysis is not the same as a forecast. A forecast is about one most likely future, whereas the scenarios show the bandwidth of what can happen. It shows the impact of internally consistent (not equally likely) possible futures. Scenario analysis is a common tool in both the public and private sector. This analysis can tell what might happen in the future and to help avoid adverse outcomes (Aaker & McLoughlin 2001; Stead & Banister 2003).

Table 1-1: the definition of the two development paths used in this study.
The two paths are based upon Bath (2014), Timmer & Kool (2014) and Wilmink et. al. (2014).

	Autonomous path	Cooperative path
Computing core	Located in the vehicle	In the vehicle and connected to external communication network
Sensors	Vision sensors, radar, laser. Car monitors the outside world	Besides monitoring, the car also communicates with other vehicles or infrastructure
Information	Not shared beyond the vehicle	Shared across multiple vehicles
Makes decisions which are optimum for	The driver	The driver or the transportation system as a whole.

In this research the cooperative and two paths are defined as black and white, which is needed in a scenario analysis. However, reality will probably be a mix of the two (somewhere in-between the

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[1] Scenario Analysis is defined as "the process of evaluation possible future events through the consideration of alternative plausible, though, not equally likely, states of the world" (Mahmoud et al. 2009, p.1).

lines of Figure 1-3). With this scenario analysis it can be seen what the differences are in the paths and which is favourable for which factors.

1.2. Transportation problem
Impacts of automated vehicles on mobility are unknown

Automated vehicles are still in the testing phase. In what exact form they will enter the market is still unknown. This makes it difficult to anticipate precisely on the actual outcomes. "Nevertheless, it can be useful to roughly estimate likely magnitudes of impact" (Fagnant & Kockelman 2015, p.172). With this information governments and other planners can make policies, which is needed rather sooner than later (Anderson et al. 2014) and helps to overcome the Collingridge Dilemma (van de Poel & Royakkers 2011, p.78). The scenario analysis to the two paths helps with this. Researching the impacts of automated vehicles comes with difficulties. This chapter will explain what the difficulties in researching the mobility impacts of automated driving are.

Impacts of automated vehicles are hard to quantify

As automated vehicles can have large impacts on society, planners want to foresee what lies ahead of them. According to the Environmental Assessment Agency (PBL), the introduction path of automated vehicles is hard to foresee (Raspe et al. 2015, p.21). PBL they even called it a black swan (an event where impacts are large, but strongly unknown), which might be a little exaggerated. According to a large expert meeting, the traffic impacts of automated vehicles are an urgent matter where the government should take its position at this moment (Alkim & Veenis 2015, p.32).

A practical and scientific knowledge gap

PBL and other planners are interested in impacts on society or on a road network (macroscopic effects), while "most papers published so far focus on traffic implications (capacity, capacity drop, stability and shockwaves) ..." (Milakis et al. 2015, p.1), so the microscopic[2] effects. What can happen on the macroscopic level is known qualitatively (less congestion, another spatial design, more safety) (Milakis et al. 2015; Fagnant & Kockelman 2015). Research papers and governmental reports often describe macroscopic effects, but these effects are often not quantified (Schultz van Haegen 2014; Litman 2014; KPMG; CAR Group 2012; Raspe et al. 2015).Three attempts are made so far, to assess the large scale impacts on mobility: an explorative study by Snelder et al. (2015), an explorative study by Tetraplan (2015) and an unfinished PhD work of Gucwa (2014). The exploratory nature of the studies does not give enough grip for policy making.

The Dutch government searches a suitable analysis method

In 2016 the next transportation policy procedure starts in the Netherlands. Then the 'Nationale Markt- en Capaciteits Analyse' (national market and capacity analysis) has to be made. In this

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[2] In Microsimulations many different individual car are simulated on a network. These cars get their own characteristics, such as the headway to others, lane changing behaviour and acceleration. Often multiple vehicle classes are used. Simulated time differs from a few minutes until one peak hour. This approach is detailed, but cannot be used on large networks, as the computation time then gets too large. In Macroscopic studies the *average* car is simulated. Based upon relations such as the fundamental diagram the speeds of a road can be calculated from the amount of cars. These models are faster, but do not capture all subtle effects of traffic. Mostly 'the average day' or 'the average peak hour' of a region or country is simulated.

analysis, the national model of the Netherlands (LMS) and the regional model (NRM), are used to investigate where the bottlenecks for road, rail and inland waterway transport are (Ministerie van Infrastructuur en Milieu 2011). However, the LMS and NRM cannot simulate the effects of automated vehicles at this moment (Snelder et al. 2015).

To change these models, the ministry of Infrastructure and Environment has asked TU Delft and TNO to research how automated vehicles can be simulated with these models. To do so, an exploratory study is done (Snelder et al. 2015). This study explained that "with the LMS not all effects from self-driving cars can be researched" [3] (2015, p.37).Therefore, workshops are held to discuss new model structures (Snelder et al. 2016).

Scope of this research

As explained above, the Dutch national government wants to investigate the *impacts automated vehicles have on mobility*, but cannot research that with the current methods. This thesis contains explorative research into the impacts of early forms of automation for the whole of the Netherlands, with a timespan until 2050. Main interest for the study will be at the Dutch national government, however, also other parties, such as other governments, might be interested. In this section the scope of the model will be presented.

Impact on mobility
The focus of this research will be change in mobility due to automated vehicles. For passenger mobility this research is interested in both the supply and the demand side. This means that both changes in how many people want to travel from A to B by which mode on what time (demand) and the capacity of the road (supply). Freight transport influences person mobility, but only the demand will be modelled of freight transport.

Explorative research: modal split, travel time losses and time of day choice
As the goal of the National Market and Capacity analysis is to see where bottlenecks occur in the coming 20 until 40 years, the large scale impacts of automated vehicles are of importance. As there is no microscopic research on all bottlenecks, a detailed model cannot be made. However, first insights in the magnitude and of the effects and how effects work together are of interest. Indicators which give this are the modal-split, the people driving during peak hours and the travel time losses. These are the same indicators similar studies use (Snelder et al. 2015; Gucwa 2014).

The whole of the Netherlands as object of study
The Netherlands is chosen as object of study because the Dutch national government is mainly interested in the outcomes of this research. Impacts of automated vehicles are first expected on highways (Snelder et al. 2015), but also the mobility impacts on other road types will be researched.

Early forms of automation: level 1, 2 and 3
As first levels of automated vehicles first will have their effects they are the researched in this thesis This research will focus on assisted, partial and conditional automation (level 1, 2, 3 of SAE International 2014). Snelder et al. (2015) also give these levels the highest priority of research. Level

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[3] Translated by author from Dutch: "Met het LMS kunnen niet alle effecten van zelfrijdende auto's worden bepaald"

3 means that the car takes over all driving tasks, but the driver still needs to be able to intervene when asked. This level is chosen since impacts of this level have a manageable amount of uncertainties. Level 4 and 5 vehicles enable car sharing, radical spatial changes and enables that new groups become mobile.

Base year 2013 - forecast until 2050

When automated vehicles will be on the market is a highly debated topic. To make forecasts expert opinions (Milakis, Snelder, et al. 2015; Shladover 2015, p.42), and comparisons with other car innovations are made (Litman 2014). Also numerous researchers and manufacturers make predictions, forecasts or guesses which often are appear in the media. Most studies lack underpinning or do not differentiate in the levels of automation. In contradiction to this, Nieuwenhuijzen (2015) has made a quantitative model for the diffusion of automated vehicles, per SAE level. His model relies, of course, on assumptions on the willingness to pay, technology development and purchase price, but is of use for this thesis. His model forecasts that in a normal economic scenario level 4 and 5 will have a penetration rate of around 5% in 2040. Above this percentage it can be expected that these levels will have significant impacts, and the model will not simulate the world correctly anymore. A slight change is made to the outcomes of Nieuwenhuijsen his research as he is optimistic compared to current years. Therefore the horizon is shifted 10 years later (why this is done is explained in chapter 1.4). Therefore 2050 is set as endpoint. Starting point is 2013.

Main problem:

Impacts of automated vehicles unknown by the Dutch government

This chapter can be summarised into one main problem. This problem is that the Dutch government needs information on automated vehicles to make smart investments or policies, but the current models cannot do the task. The main interest of the Dutch government is to explore the impact of the first levels of automation (1, 2 and 3 SAE) on mobility until 2050.

1.3. Goal and research question Transportation (part A)

In the previous section (1.2) the problem is made clear. From this problem a research goal and question are formulated. The research question is split up in sub-questions.

Research goal
The goal of this research is: *to show insight in the impacts different development paths of the early levels (1, 2 and 3 of SAE) of automated driving have on mobility in the Netherlands until 2050.*

Research question
The main question of the research is:

What are the expected mobility impacts of the different development paths of early forms (level 1, 2 and 3 of SAE) of automated driving in the Netherlands?

This main question is split up into several sub-questions. The sub-questions are:

Sub – question	Chapter presenting the results
1. Which development paths for early forms of automated driving are there?	1
2. What are the requirements for the method to assess the mobility impacts of early forms of automated driving?	3.1
3. What is the best way to model the impacts of automated vehicles?	3.2, 4 & 5
4. What are the mobility impacts of early forms of automated driving on the isolated elements of the transportation system?	5
5. What are the results of a validation test?	6
6. What are the mobility impacts of different development paths?	7
7. What lessons can be learned for policies regarding automated vehicles?	9.3
8. What lessons can be learned from this model for other models?	9.4

The two development paths (sub-question 1), which provide input for the simulations are already explained in chapter 1. In chapter 3 four requirements which the method should meet are presented (sub-question 2). In the rest of chapter 3 the preferred method is explained and a literature review is presented. Chapter 4 describes the model set-up. In chapter 5 is elaborated upon how automated vehicles are modelled. These three chapters answer sub-question 3 and question 4. After this model is created, it should be tested (sub-question 5). Chapter 6 presents the results of these tests Chapter 7 presents the results of different simulations done with the model(sub-question 6). Here the two development paths are simulated. The results of sub-question 7 and 8 are presented in the recommendation section of the conclusion.

1.4. Communication problem:
A constructive dialogue is needed in the automated vehicle innovation

The previous section focused on the impacts automated vehicles are expected to have on mobility (introduction part A). However, automated vehicles can have a wider impact than only on mobility. Automated vehicles can change the world by having impact on safety, privacy, emissions or security (Milakis et al. 2015; Timmer & Kool 2014; Fagnant & Kockelman 2015; Hoogendoorn et al. 2014). As these impacts are much wider than just the 'driver' of the vehicle, also other actors should be involved in the discussions around automated vehicles.

Automated vehicles are expected to have wide societal impacts

For many years the automated vehicle had its place in views of futurists. Recently many manufacturers showed, presented and even tested their prototypes of automated vehicles on the roads. Tesla, Google, Mercedes (Daimler), Audi, Delphi, Ford, Honda, Volkswagen, BMW a.o. (Reuters 2015; Aerts 2015; O'Brien 2014) have test licences in America to test on the public road. In other countries, such as the Netherlands, the first tests are also carried out.

The actual form automated vehicles will have is unknown
Even though the first versions of automated vehicles can be seen on the streets, this is only a glimpse of what the future might bring us. Automated vehicles are under construction and there are many different future scenarios. The core of the innovation, the software, is updated every day, visions of manufactures differ and literature describes different development paths (Timmer & Kool 2014; KiM 2015; Bhat 2014). Moreover, the business models of the automotive companies are not clear. Google even declared to innovate without having a clear business model in mind (Bergen 2015). These differences in paths or business models might look small, but can make a significant difference in privacy. The San Francisco based company Kiip for instance is building a system which makes personalised advertisements based on your location (Timmer & Kool 2014). These kind of business models have totally other consequences than just selling cars.

That the actual form of automated vehicles is not clear does also mean that input still is valuable. We are now at the point that technology still can be changed and the first impacts become clear. In a few years technology will be developed completely and the innovation can be steered less easily (Collingridge 1980).

No scientific proof for positive effects of automated vehicles
Automated vehicles are believed to be a disruptive innovation (Manyika et al. 2013; Timmer et al. 2015)[4]. Car manufacturers and futurists and governments paint pictures about a world with less accidents, less congestion and less emissions (O'Brien 2014; Schultz van Haegen 2015; Mercedes-Benz 2015). However, many of these advantages depend on how the car will be programmed: less congestion only arises when shorter headways can be held and why would there be less emissions if the car becomes a more attractive mode of transport? The sketched visions are not nonsense, but

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[4] Manyika et al. explain it a disruptive innovation should meet 4 criteria: 1) The technology is rapidly advancing or experiencing breakthroughs. 2) The potential scope of impact is broad. 3) Significant economic value could be affected. 4) Economic impact is potentially disruptive.

often show the most positive scenario. Other scenarios or paths are not unlikely. First of all, there is no scientific proof for a more efficient traffic flow or an improved road safety. Secondly, there are concerns, "liability details remain undefined, security concerns linger, and without new privacy standards, a default lack of privacy for personal travel may become the norm" as Fagnant and Kockelman (2015, p.1) explain. Still, if it is believed that the benefits outweigh the disadvantages (Anderson et al. 2014), efforts should be made to minimalize the disadvantages.

Tension between personal benefits and societal benefits
This research does not argue against the introduction of automated vehicles, but shows that there is still a large bandwidth in which automated vehicles can be developed. Besides technological progress, the automated vehicle should also bring societal progress or benefits. This progress can be split up in personal benefits for the driver and benefits for society as a whole (Anderson et al. 2014). The consumers of a self-driving vehicle are mainly interested in the personal benefits. However, with their purchase and use of an automated vehicle they also influence others. Timmer and Kool (2014) for instance warn that the public and interest groups should be part of the discussion as "their input is essential for societal embedding of the smart car."[5]

Reasons to involve the non-consuming part of the public
Not only the consumers, but also the non-consuming part of the public (the other road user such as the cyclist or the 'normal car' owner) should be involved. There are three types of reasons for. These are substantial, instrumental and normative (Fiorino 1989; Stirling 2008).

The *substantial* argument entails that public involvement in science leads to better decisions. Input from non-scientific sources can broaden the insights. The public can bring other insights than just experts, especially as they have a non-rational way of reasoning (Roeser 2012).

The second reason for participation is the *instrumental* argument. As people directly can state what they like or not (Sutcliffe 2011, p.11) and therefore prevents blockings or non-acceptance (Irvin & Stansbury 2004). Besides that, they can bring insights and therefore help the innovation (van de Poel 1999; Irvin & Stansbury 2004) especially as they have a non-rational, but emotional way of reasoning (Roeser 2012, p.812). As in later stages the public uses emotional arguments to judge a technology, it is better to take them now into account. Lastly, the public can force with blocking power (demonstrations etc.) that innovations are not introduced, which for instance happened with genetically modified foods. Involving the public can help to overcome this (de Bruijn & ten Heuvelhof 2008; von Schomberg 2013). For automotive companies this means that by involved the public, they can bring a product to the market which is more alighted with the desires of the customer. Inclusion of stakeholders can decrease the chance of non-acceptance of an automated vehicle and can improve the social desirability.

The normative argument reasons from a democratic principle. It can be argued that the technology co-shapes the world (Winner 1980; Guston & Sarewitz 2001) and therefore influences the domain of more than just the owner. So, for democratic reasons the whole public should have a say in the how

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[5] Translation by the author from Dutch: "Waarborg de inbreng van burgers en maatschappelijke organisaties in het innovatieproces. Hun betrokkenheid is onmisbaar voor de maatschappelijke inbedding van de slimme auto."

their future world should look like. The same reasoning is used in legal arguments, mostly for environmental purposes (see Aarhus Convention 1998, art. 6)). This convention does not directly hold for automated vehicles, it explains that the public can argue that they are affected and therefore "stakeholder"[6] (Timmer & Kool 2014, p.53). This covers that public has right on "public participation in environmental decision-making" (Aarhus Convention 1998, art 6).

The innovation in the light of Responsible Innovation (RI)

The process of developing an automated vehicle is a hard, with many aspects of a wicked problem (Rittel & Webber 1973). The different aspects are: the introduction of automated vehicles is novel; there is no optimal solution so a satisfying has to be found; it is a one shot operation, which has to cope with the Collingridge Dilemma (Collingridge 1980); there is an endless set of solutions; which has no stopping rule and the problem is not completely understood after the formulation of a solution.

Actors in the automated vehicle innovation

Irvin & Stansbury (2004, p.56) name involving the public as a strategy to break gridlocks. Cuppen (2012) explains that involvement of many actors helps to overcome wicked problems. As the impacts of automated vehicles are wide, there are also many actors in the automated vehicle innovation (Timmer & Kool 2014, chap.10). Manufacturers, government, the public but also insurance companies or public transport companies play a role. To narrow the scope of this research only actors with decision power (de Bruijn & ten Heuvelhof 2008, p.38) and the public as a whole are taken into account. The actors with decision power are the *government* (as they are owner of the roads and allow cars on the road), the *manufacturers* (as they design and produce the cars) and the *consumers* (as they buy the cars). These are the direct involved actors. In another study on vehicle automation these are also mentioned as the most important actors (Walta 2011). For the substantial, instrumental and normative reasons mentioned earlier *the non-consumer*[7] is also involved in this research. In figure 1-4 an overview is sketched of the actors. The future consumer and the non-consumer together form *the public*. Timmer and Kool (2014, p.32) explain that currently "… the public barely plays a role in the development of a smart car […]. Or even stronger, they are the notable absence."[8]

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[6] Translation by the author from Dutch: "belanghebbende"

[7] The term *non-consumer* might need some explanation. This is the part of the public which does not have an automated vehicle (yet), but is affected by automated vehicles. The effects they feel can both be positive or negative. Their travel time can also be optimised and their cities more liveable, but they also might get an alienated feeling or distrust the safety.

[8] Translated by the author: "…burgers nog nauwelijks een rol van betekenis in de ontwikkeling naar de slimme auto (of dit nu de coöperatieve of de robotauto betreft). Sterker nog, zij zijn opvallend afwezig."

table 1-2: the four actors taken into account in this research (table is based upon Timmer & Kool 2014, chap.10 and own insights)

Actor	Role
The national Government	Owns the road network and can allow which vehicles are allowed to drive on it. They also can formulate policies or subsidise innovations. Important parties are the ministry of I&M, Rijkswaterstaat and the RDW. This research focusses on them, nevertheless are provinces and municipalities getting more and more interested in the innovation.
Manufacturers	The manufacturers of automated vehicles are mainly traditional car companies and a few newcomers. Around the car manufacturers are several tiers of suppliers. Those are left out of the research scope as they do not have final decision power about the design of a car.
Consumers	The part of the public that will buy an automated vehicle in the future.
Non-consumer	This is the part of the public that will not have an automated vehicle. Gradually the two parts of the public will change in size, however, as the transition is expected to take more than 40 years (Litman 2014; Nieuwenhuijsen 2015) both groups are of interest.

A few players who are left out of this research are the interest groups, the research institutes and universities. These players have a neutral role, or represent another actor (mostly a part of the public for interest groups). Others, like public transport companies or insurance companies play a too small role to take into account.

Schematic overview of all actors
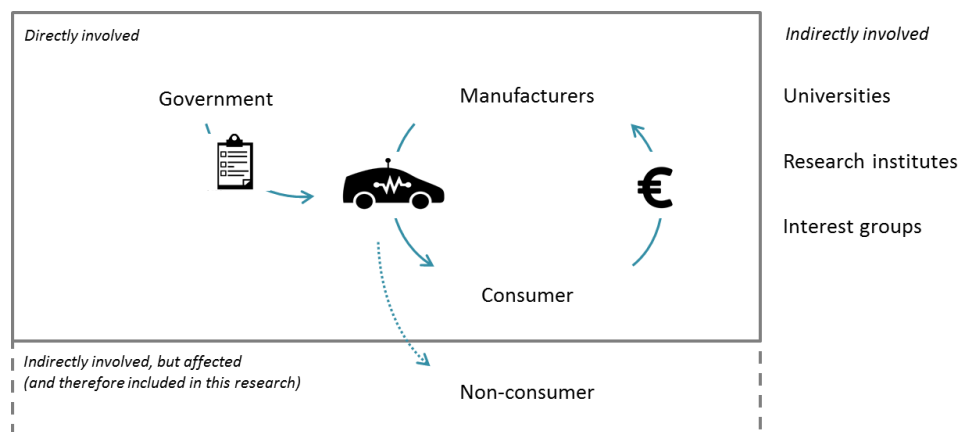
figure 1-4: The car manufacturers produce a car for the consumers, the government can make regulation for this car. These actors are directly involved as they have decision power. The goal of this research is to also include the non-consumer into the decision making.

Representing the public

Who or what is the public is a debatable topic (Dewey 1927). Dewey discusses that the public has multiple forms. Depended upon the case the public forms groups. In this case the groups are formed as consumers and non-consumers. Of course other groups can be formed, especially within the non-consuming part: cyclists, parents of children, environmental aware people or old-timer owners. Some of these groups are represented by an institution, such as environmental interest groups. In this

research the people in the group are researched, instead of organisations representing them. Organisations are not formed (yet) or too broad (ANWB) and the people are the ones having the values and reasoning from emotion. So, especially substantially and instrumentally the people should be involved in this phase instead of the organisations representing them.

The irresponsible dimensions of the automated vehicle innovation
The scientific and governance field of *Responsible Research and Innovation* aims to take all potential impacts on the environment and society into account (Sutcliffe 2011, p.3). Stilgoe et al. (2013) define 4 criteria to determine whether an innovation is responsible. If the automated vehicle innovation is seen in the light of these criteria, it can be argued that it cannot be called *a responsible innovation*. Von Schomberg (2013) goes further, he defines 4 criteria to see if an innovation is *ir*responsible. It can be concluded that the automated vehicle innovation shows signs of irresponsibility. An essay with a longer discussion on all points can be found in appendix G. The five most striking points of comparing the automated vehicle innovation to the criteria are explained here below:

1. The innovation shows signs of a policy-pull and a techno-push. Both named by von Schomberg (2013, pp.14 & 17) as signs for irresponsible innovation. Governments (Schultz van Haegen 2014; Timmer & Kool 2014) but surely the automotive industry is very enthusiastic about automated vehicles (Timmer & Kool 2014; Bernhart et al. 2014). Especially the automotive industry has invested millions (Timmer & Kool 2014), but the public is not unanimously enthusiastic. After comparing 10 recent surveys studies Kyriakidis et al. (2015, p.3) conclude that "…people also indicate a non-negligible level of reluctance" for automated vehicles.
2. Another irresponsible dimension von Schomberg (2013, p.16) names is the "neglectance of fundamental ethical principles". Fagnant and Kockelman (2015, p.1) address three concerns which are not solved at this moment "[l]iability details remain undefined, security concerns linger, and without new privacy standards, a default lack of privacy for personal travel may become the norm." All three concerns deal with fundamental ethical principles.
3. Responsible innovations require transparency (von Schomberg 2013, p.19; Stilgoe et al. 2013, p.1570), as a starting point for reflexivity, inclusion and responsiveness (all dimensions of Stilgoe et al). Currently car manufacturers share their visions and test publically, but in their communication they only highlight advantages and lack communicating possible risks or downsides. Besides that, some parts of the visions are missing, for instance the business models. Leading example is Apple who has complete radio silence around its self-driving car program (Harris 2015). In his literature review Aerts (2015, chap.2) explains that especially the autonomous path is characterised by 'competition' and 'secrecy'.
4. In the light of precautionary measures (von Schomberg 2013, p.19) policies for automated vehicles should be made rather sooner than later (Anderson et al. 2014, p.4; Fagnant & Kockelman 2015, p.179). What now happens is what Owen & Goldberg (2010, chap.1) call: "significant time lags between the development of novel innovations, understanding their wider impacts and subsequent governance". In order to make these responsible, the public should have a voice in making these policies. This however, a public debate is currently lacking (Timmer & Kool 2014).

5. Inclusion of stakeholders (Stilgoe et al. 2013, p.1571), so let stakeholders participate in the innovation process and do something with their inputs (responsiveness, Stilgoe et al. 2013. p.1572), are done in some governmental policy making (internet participation), but there are no car manufactures with programs like these, or at least not known.

Research scope

Focussing on all five points is too much for one thesis. The most striking points are point 2 and 5: the non-inclusion of stakeholders and therefore the risk of harming their fundamental ethical principles. This is strengthened by the advices Timmer&Kool (2014, p.35) have. They explain that the government should "[g]uarantee the input of citizens and interest groups in the innovation process. Their involvement is essential for the societal acceptance of the smart car"[9].

This research focusses on these two aspects. A new method, based upon Value Sensitive Design will be created and tested. If this method is performed on large scale by car manufactures or policymakers the automated vehicle innovation can become more responsible. By improving upon these points it "….allows options to be kept open, it is the antidote to lock in and path dependence." (Owen et al. 2013, p.35). It therefore helps to overcome a wicked problem.

Main problem

The automated vehicle is an innovation that can change the whole transportation system (Milakis et al. 2015) and can have large impacts on society (Fagnant & Kockelman 2015; Litman 2014). The impacts are expected to be positive, but, there is no scientific proof for this. Besides that, the innovation can have downsides, which are not communicated widely at this moment. Because of this, the public should be involved in the development, which is not happening at this moment. Non-inclusion of important stakeholders entails the risk of neglecting fundamental ethical principles. For these reasons, and others, this innovation shows signs of an irresponsible innovation.

In this research a method will be developed to set up a constructive dialogue between the 4 important actor groups (the government, the car manufacturers, the consumers and the non-consumers). By involving these actors, their fundamental ethical principles can be used as starting points for design. This dialogue thereby helps to form a socially accepted starting point for the design of future automated vehicles. This dialogue is not meant as a method to change the publics' opinion in order to increase awareness or sales. This dialogue is meant to research opinions of all actors and shape the outcome of the innovation.

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[9] Translated by the autor from Dutch: Waarborg de inbreng van burgers en maatschappelijke organisaties in het innovatieproces. Hun betrokkenheid is onmisbaar voor de maatschappelijke inbedding van de slimme auto

1.5. Goal and research question Communication (part B)

From this problem a research goal and question for part B can be formulated.

Goal Communication
The goal of this research is: *to develop and test a constructive dialogue method with multiple actors to give input for future designs of automated vehicles.*

Question Communication
The main question of the research is:

To what extent can a constructive dialogue method be developed to give input for future designs of automated vehicles?

This main questions is split up into five sub-questions. The sub-questions are:

Sub – question	Chapter presenting the results
1. Which criteria from literature should the method meet to be a constructive dialogue method?	10
2. What values, of the relevant actors, are at play in the development of automated vehicles?	12.1
3. What is the relative importance of the identified values per actor?	12.1
4. To what extent can one common value profile be created in a constructive dialogue?	12.2
5. Which value tensions become clear when the values are specified to design input?	12.2

The results of the first sub-question, which sets the criteria, is shown in chapter 10. In chapter 11 the method is described. In chapter 12 the results of the method are discussed. Section 12.1 shows the values at play (sub-question 2) and the relative importance of these values. In section 12.2 the results of the constructive dialogue are shown. The results are a common value profile, and value tensions between the actors.

Part
A

Mobility effects of automated vehicles

Short summary and reading guide

The goal of this study is to gain insight in the effects early forms of automated vehicles (level 1, 2 and 3) may have on the mobility in the Netherlands. This should give policymakers insights for transportation and infrastructural policies. The study is performed to the two development paths mentioned in literature: autonomous driving and cooperative driving.

In the first chapter of this part (chapter 2) an overview of the modelled system is showed. This chapter explores which concepts need to be modelled. In chapter 3 criteria are set for the model. The chapter explains that the model should be explorative; should model automated vehicle as different user class; and the model should research both supply and demand. Complementary, the preference for System Dynamics (SD) is presented.

Chapter 4 describes the structure of the SD-model. In this chapter the four steps of the model are explained in detail. Chapter 5 clarifies how automated vehicles are modelled. Three vehicle classes are modelled (level 0, level 1 & 2 and level 3) which differ on value of time, fuel consumption and PCU value (capacity impact). Literature on microscopic studies is translated to model variables for the high abstraction level used in this model. In chapter 6 the model is tested. Among other tests a comparisons is made with other models simulating automated vehicles. These test show that the model can be used for explorative research.

For both the autonomous and the cooperative development path experiments are done, these are shown in chapter 7. In chapter 8 the results and model set-up are discussed. Chapter 9 contains the conclusions and recommendations.

2   Mobility impacts of automated vehicles

In 1908 Henry Ford started the mass production of cars. The Ford model T and his successors from Ford and competitors changed the transportation system radically: more people became mobile and average traveling speeds rose (Baaijens et al. 1997). Since then the basic principles of the car stayed the same: a driver in charge, steering with his hands and adjusting the speed with his feet.

10 years before the first mass production the Dutch minister Cornelis Lely announced in the paper *het Algemeen Dagblad* a test with a car, to transport mail from Amsterdam to Leiden. It would go 15 km/h and could carry 1000 kg and "would be a proper shelter for rain and wind" (Nieuwe Amsterdamsche Courant 1898, p.1). Recently, 120 years later) the current Dutch minister Schulz announced tests, this time with automated vehicles (Schultz van Haegen 2014). This innovation could again change the transportation system radically. This chapter elaborates on which factors in the transportation system could be changed by early forms of automated vehicles.

2.1.   The transportation system and impacts of automated vehicles

Before impacts automated vehicles have on mobility can be investigated, mobility has to be defined. Literately mobility means movement, in this context it means the way people move themselves. Also goods can be moved, but in this research the focus will be at passenger transport, therefore goods will be researched less elaborately. Still, both interact, thus the transportation of goods cannot be neglected.

The mobility system is often defined as a supply and demand side. The supply is the amount of capacity a system has. For roads this is the capacity of a lane (for instance 2000 vehicles / hour). The demand is how many trips are made, for instance per day or per hour.

Impacts of automated vehicles on this system

Milakis et al. (2015) give a good overview of which the elements of the transportation system are influenced by the automation of the car fleet. The Milakis research and others (Snelder et al. 2015; Fagnant & Kockelman 2015; Hoogendoorn et al. 2014) make clear that both the supply and the demand are influenced by automated vehicles. Milakis et al. (2015, p.3) present a Ripple model, shown in figure 2-1 which explains the impacts per SAE level. They explain that: "[....] we might expect implications to extend up to the first ripple for level 3 (conditional automation; according to SAE International, 2014) and up to the third ripple for level 5 (full automation)."
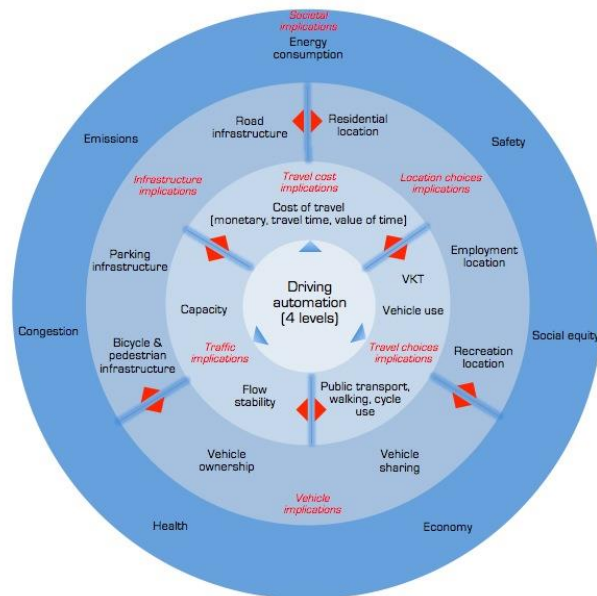
figure 2-1: Ripple model shows the impacts of automated diving. Early forms (1, 2 and 3) have impact on the inner ripple, later versions also on the outer ripples (Milakis, van Arem, et al. 2015).

Elements affected by automated driving

The elements, which Milakis et al. name level 1, 2 and 3 have impact on are[10]:

The "use of vehicles", but also "public transport, walking, cycling"
Automated vehicles enable that 'drivers' can spend their time differently, travel faster or travel cheaper. Therefore the preferences for modes can change. This is normally modelled as a change in travel costs (monetary, travel time and value of time). Not only Milakis et al. name this aspect, also other literature describes this (Snelder et al. 2015; Gucwa 2014; Litman 2014). From these papers we conclude that there are three effects that are changed by automated vehicles: value of time[11], travel time for cars and monetary costs (like fuel efficiency).The travel time is a second order effect of other effects such as preference for mode or capacity effects. Another effect that is described to a lesser extent is the comfort, sometimes this is meant as a change in value of time, sometimes as other types of comfort. Often this stays ambiguous. In chapter 5 more information about the chosen parameters for automated vehicles will be shown.

The "capacity" and traffic "flow stability".
As automated vehicles can hold shorter headways than human drivers, the capacity of a road can increase. Another theory is that due to safety reasons cars need to hold larger headways, which decreases the capacity of a road. Besides capacity also related traffic flow effects can change. Hoogendoorn et al. (2014) and Snelder et al. (2015) state that the automated vehicles can influence the capacity drop, lead to a higher flow stability or a more efficient use of the network.

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[10] For all effects holds that other sources name the effects, but Milakis et al. are the only ones linking the effects to the levels of SAE international.
[11] Other research, for instance Snelder et al. (2016) do not speak of a change in value of time, but a change in the penalty for the travel time. In this way multiple groups can be separated more easily. As other research speaks of the value of time this term is used here.

The "Vehicle kilometres travelled"
Milakis et al. (2015) explain that because of enhanced accessibility in more distant locations the amount of kilometres travelled per trip by car can be influenced. Also spatial changes can contribute to this. If this is possible to model, this aspect has to be taken into account.

Both heavy goods vehicles and passenger cars
The focus of the model is passenger mobility. Nonetheless, trucks also influence the travel times of passenger cars. As a significant percentage of the road traffic consists of heavy goods vehicles (Goudappel 2014), therefore they should also be modelled. Only the demand of trucks is modelled, the supply is set constant.

Peak hour travels
Automated vehicles can also influence the departure time choice. The decrease of congestion or the possibility to work in the car might make traveling during peak hours more attractive (Gucwa 2014; Snelder et al. 2015). As the Netherlands almost only encounters traffic problems during peak hours, it is expected that the mobility effects of automated vehicles are mainly in the peak hours. Therefore the number of travels in peak hours will be calculated, and not set as a fixed share as is done in other investigations (Heyma et al. 1999c). The calculation of the speed will only be made for peak hours.

Model concepts which are influenced by automated vehicles

From this list the following aspects, which should be captured by the model, can be extracted. The aspects on which normal vehicles differ from automated vehicles are: 1) the value of time, 2) the capacity (and related effects) and linked travel time, and 3) the fuel costs. Next to this the trip generation can also be influenced. If the model structure allows modelling trip generation, it is desired to be modelled.

The mentioned changes will influence the *modal split*, the *time of day choice* and the *assignment*[12]. This means that both the supply (how many trips from A to B) and the demand (how much capacity the roads have) should be modelled, as well as the feedback between them. This feedback is important as in this way the updated travel time (due to capacity or demand changes) can be taken into account in the preference for a mode or departure time. It is desired that automated vehicles are modelled as a separate mode. For this new vehicle type the value of time and preference can be changed. In other research (Gucwa 2014, Tetraplan 2015 and Snelder et al. 2015) the average vehicle is changed, instead of modelling a new mode.

2.2. Other variables with effects on mobility

The purpose of this study is to gain insight in effects of automated vehicles on mobility. However, these effects should be modelled together with other effects influencing mobility to compare the magnitude. As input for other factors influencing mobility (the exogenous inputs) the LMS *starting points document* (Ministerie van Infrastructuur en Milieu 2015) is taken. In this document the Dutch

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[12] The assignment is the modelling step where supply and demand meet. Here the volume (how many trips) are related to the capacity. Often the assignment is done in a network, where per road the ratio between intensities and capacities are calculated.

Ministry of Transport explain what is taken into account in their countrywide model, the LMS. The same starting points will be used in this research. The exogenously changing variables are: population growth, new roads built, prices in public transport, travel time of trains and the car ownership. In chapter 4.7 all exogenously changing variables will be discussed in more detail.

The nature of this research is strongly explorative, as the field of automated vehicles is still full of uncertainties. As this research explores the impacts of automated vehicles, the uncertainties caused by automated vehicles are the main interests. Of course, also other variables (demography or new roads) influence mobility, but central in this thesis are the different development paths and their uncertainties for automated driving.

2.3. Specification of the model

From this analysis the nature of the model can be specified:
- The focus should be on exploring impacts of automated vehicles on mobility, therefore other factors influencing mobility have to be taken into account roughly.
- The model should focus on passenger transport and take freight transport into account in a more simplistic way. The demand of freight transport can be set constant.
- Both supply and demand should be modelled.
- The model should focus on peak hours.
- The mode choice, time of day choice and the assignment should be modelled as these concepts are influenced by automated vehicles. The trip generation should be modelled as demographic changes then can be taken into account.

The next chapter (3) explains which method is most desirable to model this system, chapter 4 explains how the model is built up and chapter 5 specifies the settings for the two development paths: cooperative and autonomous driving.

Reading guide of the rest of the report
In the next chapter (3) different models will be compared and one will be chosen. In chapter 4 the set-up of the created model will be explained. Chapter 5 explains how in this model automated vehicles are modelled. Tests with the model are shown in chapter 6. The next chapter (7) experiments with the model are shown. Hereafter follows the discussion (8) and the conclusion (9). In the conclusion also recommendations are presented.

Overview of the next chapters

Overview of the System	Choice of the method	Set-up of the model	Simulating automated vehicles
2	3	4	5

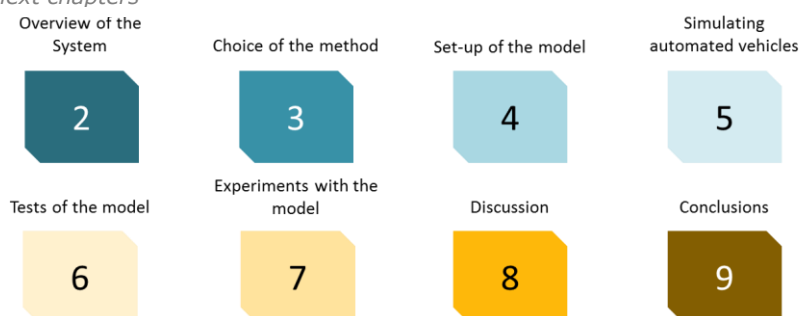| Tests of the model	Experiments with the model	Discussion	Conclusions
6	7	8	9

figure 2-2: Set of the part A of the report

3   Method to determine the impacts of automated vehicles

There are two main candidate methods to research the impacts of automated vehicles: Macroscopic Models and System Dynamics. In this chapter first requirements are set followed by an explanation of the two methods and some less probable methods. The chapter finishes with an explanation why System Dynamics is the preferred method for this research and a short literature review on System Dynamics.

3.1.   Four requirements for the model

In order to make long term analysis to the effects of early forms of automated driving, a forecasting approach needs to be chosen. Forecasting the impacts is hard as there are many linked effects. Besides the complicating factors of many linked effects, the impacts also need to be quantified. A computer model is most likely to be needed to simulate the effects. In this section the requirements are set for the model. This answers the second sub-question: *what are the requirements for the method to assess the mobility impacts of early forms of automated driving?*
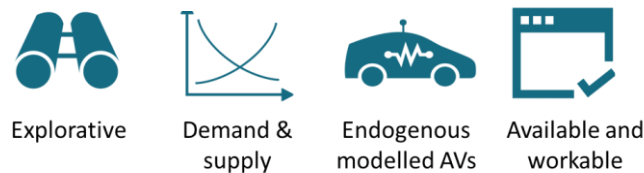
Requirements for the model

| Explorative | Demand & supply | Endogenous modelled AVs | Available and workable |

figure 3-1: the four requirements for the model.

The requirements that are set for the model are that it should 1) have an exploratory set-up to test policies and development paths, 2) model both the demand and supply, 3) model automated vehicles endogenously and lastly should be 4) available and workable.

1) A model to exploratory research the impact of different paths (desired outcomes)
The impacts automated vehicles have on society are unknown and hard to quantify (Milakis, van Arem, et al. 2015). The model should be a first step to research the combined effects. This means that it should be more exploratory or reflective than exact. The model should try to be a first step to quantify the inner circle of the ripple model (Milakis, van Arem, et al. 2015).

The research question, mobility effects of automated vehicles, is full of uncertainties. This makes a detailed forecast impossible to make. As not only the impacts are uncertain, but also the design of future automated vehicles are uncertain, both should be researched. Furthermore, the model should be able to test different policies.

In order to assess how automated vehicles change mobility the model should at least calculate *the modal split, the number of trips made in an average peak hour, the travel time changes for cars* and *the vehicle kilometres travelled by car*. These variables give insights on a high abstraction level and are also outcomes of the studies of Gucwa (2014) and Snelder (2015), which gives the possibility to compare the results.

2) Demand and supply (desired inputs)

The second requirement is that the method should both incorporate the demand (how many trips are made from where to where) and the supply side (how much capacity the network has). As is explained in chapter 2, the model should take changes in value of time, travel time and monetary costs for cars into account at the demand side. Both for the departure time choice and the mode choice. In addition, for the supply side the changes in road capacity automated vehicles cause should be modelled. Besides supply and demand, also the feedback between them should be researched, because the current travel times influence the mode choice or departure choice.

3) Automated vehicles endogenously modelled

The third requirement is that the effects automated vehicles have should be modelled endogenously. This means that the value of time, fuel costs or impact on capacity only changes for the cars which are automated. Therefore should the different levels of automated vehicles be modelled as different vehicle classes. In current automated vehicles studies the value of time is changed for all cars (Gucwa 2014; Snelder et al. 2015; Tetraplan 2015). In this way, the 'average car' is changed instead of a change for a certain group. By modelling the effects endogenously also mixed traffic (different levels on one road) can be simulated more precisely.

4) Available and workable

Lastly, not all models are available to work with, or are too large to handle in one investigation. Therefore, the model that is used should be available and workable.

3.2. System Dynamics suits better than a Macroscopic approach

The high abstraction level and the requirement to model both demand and supply directly attract the attention to two methods: Macroscopic models and System Dynamics. Macroscopic models are traditionally used for this type of research. In the nineties TNO developed the ScenarioExplorer (Heyma et al. 1999a) which is a System Dynamic approach to similar questions. Besides these two methodssome other models are explained briefly.

Macroscopic simulation models

Macroscopic models simulate aggregated traffic. They do not model individual vehicles, which is done by microscopic models, but average traffic streams. Mostly used relationships are between densities, average speeds and traffic flows. The term Macroscopic deals with the type of assignment that is performed. Still, also the demand (generation, distribution, mode choice) should be researched. This is often based on person, household or zonal level.

Traditionally, long-term transportation forecasts are made with macroscopic transportation models. In the Netherlands, the countrywide LMS (het Landelijk Model Systeem) and the regional NRM (Nederlands Regionaal Model) from Rijkswaterstaat are the most commonly used tools by governments. This makes this approach also the most logical way to model automated vehicles.

1) A model to exploratory research the impact of different paths (desired outcomes)

Macroscopic models are used nowadays to investigate the effect of different policy measures or infrastructural changes. The models used in practice are complex and strongly disaggregated as they consider many variables. This leads to long run times (LMS takes half a day to run), which makes it

hard to do explorative research with the models. Besides, the models are detailed, which makes them hard to change and less suited to handle questions with a large amount of uncertainties. So, the Macroscopic models can research the impacts of different policies and scenarios, but cannot be called exploratory.

2) Demand and supply

The LMS and NRM are the mostly used Dutch countrywide models taking both the demand and supply into account. Other Macroscopic models start with an OD-matrix and only focus on the assignment (or assignment and time of day choice). Advantage of macroscopic models is that they make use of an explicit network. A combination of the LMS and a dynamic assignment model can be used. However, the feedback between both is then hard to model. Inconsistencies with the origin-destination matrix can also arise if two different models are used.

3) Automated vehicles endogenously modelled

To model the automated vehicles endogenously different vehicle classes have to be created. In existing macroscopic models this is hard. Three macroscopic automated vehicles studies have been done. One by the TU Delft and TNO with the LMS (Snelder et al. 2015), one by Tetraplan for the Copenhagen region (Tetraplan 2015) and the last one in California by making use of the Metropolitan Transit Commission's: *Travel Model One* (Gucwa 2014). These studies do not model new modes or car types, but change the attributes of the regular car. At the start of 2016 TNO investigated how the LMS had to be changed in order to simulate different vehicle types (Snelder et al. 2016). The suggested changes are hard and time consuming to model.

4) Available and workable

The LMS (and NRM) are complex models and therefore hard to make changes to. Especially because a new mode has to be modelled (Snelder et al. 2016, pp.11–13). Alternative macroscopic models have a smaller scope (regional models) or only simulate the assignment. Feedback from the assignment back to the mode and time of day choice becomes problematic as multiple models are used.

FINDINGS ON MACROSCOPIC MODELS

Macroscopic models are currently the most logical approach to assess different development paths and policies have. However, they have their downsides. As the models are complex and large, they make modelling automated vehicles endogenously complex. This complexity of the models also makes exploring hard as many parameters need to be changed. Therefore, the model could be used for the task, but then substantial changes to current models have to be made.

System Dynamics

System Dynamics is a method to study behaviour of complex systems over time. Pruyt (2013, p.1) explains that System Dynamics "is a method to describe, model, simulate and analyse dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies". The method deals with relations between system elements and feedback in the system. It can show behaviour over time of different elements in a system (Sterman 2000). The System Dynamics method can be applied to a wide range of fields (Pruyt 2013), but is rarely used to research personal mobility (Shepherd 2014). Nevertheless, there are some examples (Heyma et al. 1999a) or

papers arguing for more use of System Dynamics in transportation research (Abbas & Bell 1994; Shepherd 2014).

1) A model to exploratory research the impact of different paths (desired outcomes)
Explorations of different policies and scenarios is the main application of System Dynamics (SD) (Pruyt 2013; Sterman 2000; Abbas 1990). Abbas and Bell (1994, p.375) argue that SD can be used for "exploration and analysis of complex systems", and state that its therefore very suitable for transportation purposes. SD has already proven to be a helpful modelling approach to explore different scenarios in transportation in the ScenarioExplorer (Heyma et al. 1999a; Malone et al. 2001).

2) Demand and supply
The boundaries of a System Dynamics model can be as wide as desired, so both demand and supply can be modelled, with the feedback in-between. This has been shown by the ScenarioExplorer (Heyma et al. 1999a) and is suggested in the paper of Horváth (2012). Problems might arise in the trip generation, since they are often strongly disaggregated. They could also arise during the assignment, because of their need of an explicit network. (Horváth 2012). However, earlier studies have already found a way to work around these problems (Heyma et al. 1999a).

3) Automated vehicles endogenously modelled
Automated vehicles can be modelled endogenously. System Dynamics makes it possible that new modes can easily be added. Because there are still lots of uncertainties about the microscopic effects of automated vehicles, SD is a suitable approach. SD makes it possible to take sensitivities of parameters easily into account.

4) Available and workable
There is no System Dynamics model available to simulate mobility in the Netherlands. The in 1999 developed ScenarioExplorer (Heyma et al. 1999a) can be used as a basis, but the concept should be changed in order to simulate automated vehicles. Furthermore, it is difficult to gather input data to construct the base year and to calibrate the model.

Conclusion on System Dynamics models
System Dynamics is suitable to explore policies and scenarios. Also endogenously modelling both supply and demand is possible. The downside of System Dynamics is that there is no model available, so a new model should be made.

Other options for models

System Dynamics and Macroscopic models can be used and have been used to simulate countrywide traffic (Heyma et al. 1999a; Snelder et al. 2015). Nevertheless, also other methods could be used. Still, their geographical scale is often too small. Microscopic (simulating the individual vehicle) and Mesoscopic (simulating characteristics of groups of vehicles) simulate smaller areas than are desired. Still, the effects can be scaled up. Moreover, the demand side has to be modelled. If these models are used, another demand model has to be run, then simulations in a microscopic model have to be done, these results have to be scaled up and fed back to the micro simulations. This is quite time consuming and circuitous.

Thus, for other types of research (on smaller scale) microscopic and mesoscopic simulations have their benefits, but in order to simulate both supply and demand for the whole of the Netherlands other models such as the LMS or System Dynamics are more suitable.

The chosen method: System Dynamics

From the discussed methods the System Dynamics approach seems to be the most suited to the requirements. System Dynamics (SD) has the advantages that different policies and scenarios can be assessed in a short time. Besides this SD can model both demand and supply with a continuous feedback between them. The possibility to model automated vehicles endogenously is a benefit, which only can be found in SD. In table 3-1 SD and Macroscopic models are compared per criterion.

table 3-1: System Dynamics is the preferred approach to model mobility effects of automated vehicles as it is strongly explorative, supply and demand can be modelled and the ease of modelling automated vehicles endogenously.

Criteria	Macroscopic models	System Dynamic models
To explore different scenarios	More detailed than exploratory. Takes long to run and therefore to assess different scenarios and sensitives.	Strongly exploratory. Will never reach details, but is meant to test the impact of different policies. With simple clicks scenarios can be changed.
Research both demand and supply	Yes, with lots of detail.	Yes. However, trip generation and assignment can be a problem.
Automated vehicles endogenously modelled	Is hard but not impossible.	Can be done. And sensitivities can be taken into account.
Available and workable	Traditional models are large, complex and hard to change.	A new model should be made.
To sum up	Can do detailed investigations on an explicit network, but has a long running time. Hard to model automated vehicles endogenously.	Aggregated strongly explorative approach which can quickly investigate impacts of endogenously modelled automated vehicles in different scenarios.

As there is currently no System Dynamics model available to assess transportation impacts in the Netherlands a new model should be designed. In the next paragraph a background on SD and transportation is given. The next chapter discusses the set-up of the model in detail.

3.3. A literature review on System Dynamics

As society gets more complex and more interconnected, a holistic, system-oriented approach is needed to see the behaviour of systems (Repenning 2003, p.325). System Dynamics is such an approach. System Dynamics makes use of causal relationships between the elements of a system. By

quantifying these relations the behaviour of a system over time can be researched (Pruyt 2013). System Dynamics can be applied in a variety of cases, from simple systems like companies to large systems like the climate of the whole earth (Meadows et al. 1972; Sterman 2000). Or as in this case: to model effects of automated vehicles.

System Dynamics and transportation
System Dynamics is not often applied in road passenger transportation. After the paper of Abbas & Bell in 1994, who promoted the use of System Dynamics in transportation, Shepherd (2014) made a list of all System Dynamic models used in the field of transportation in peer-reviewed papers from 1995 until 2013. Most studies investigate new fuel types, maintenance, goods or policies. However, none of the papers Shepert finds describe the effects of automated vehicles or passenger transportation in the way that is needed here.

Nevertheless, two papers Shepherd does not name elaborate upon calculating both supply and demand for passenger transport in a country (based on a four-step-model). In the nineties the Dutch research organisation TNO developed the *ScenarioExplorer* (ScenarioVerkenner in Dutch) (Heyma et al. 1999a; Malone et al. 2001). This model was used to investigate the effects different policies would have on mobility the coming 50 years.

System Dynamics and automated vehicles
The ScenarioExplorer was already used to forecast impacts of automated vehicles in the nineties by van Arem and Smits (1997). This study indicates that System Dynamics is a useful tool to assess automated vehicles. However, van Arem & Smits used data from experts (where currently literature is available), model vehicles exogenously (which can be made endogenously) and evaluate policy scenarios (where this thesis is interested in technical scenarios or development paths). Still, insights from the study can be used. Unfortunately, the ScenarioExplorer is not up to date and written for 16-bit processors in an old software language (Heyma et al. 1999b). Nevertheless, the model built up of the model Heyma et al. (1999d) present can be used as inspiration for the to be created model.

Recently, the topics System Dynamics and automated vehicles have been combined in another master thesis (Nieuwenhuijsen 2015). This thesis has to goal to investigate the market introduction of automated vehicles, which differs from the objective in this thesis. The results of the Nieuwenhuijsen research can be of input for this thesis.

System Dynamics will not replace Macroscopic models
The exploring character of System Dynamics suits the questions of this thesis. However, to answer all future questions, more in depth studies and more in depth models are needed. System Dynamics is a suitable approach to explore different policies or scenarios over a time span of 50 years. Although, for detailed analysis macroscopic models stay the preferred option. Insights from modelling System Dynamics nevertheless can be used in creating a macroscopic model for automated vehicles.

4 Structure of the System Dynamics model

System Dynamics is the chosen method to model automated vehicles in this research. This chapter explains how the system is modelled the next chapter (5: *Automated vehicle model variables*) discusses how automated vehicles are modelled. In this chapter first, the general structure of the model is described, with including the most important elements and feedback loops. The following paragraphs present how the separate elements are modelled. Each paragraph starts with an italicized summary. The model is called the System Dynamics-model or the SD-model.

4.1. General structure of the model

The goal of the System Dynamics model is to evaluate the mobility effects of early forms of automated driving in the Netherlands from 2013 until 2050. For each year, the modal split, the amount of people traveling in the peak hours, and the travel time of cars on a relation (a link consisting of different roads between origin and destination) are calculated (see 3.1 Requirements). As System Dynamics is an aggregated approach, the Netherlands is divided into 6 zones. Therefore, the model does not make use of an explicit network, but makes use of characteristic relations. The model takes the demand and the supply and feedback between them into account.

Scoping of the model: bull's eye diagram
In System Dynamics bull's eye diagrams are used to indicate what is endogenously modelled, what is exogenously modelled, and what is left out of scope (Sterman 2000). In figure 4-1 the bull's eye diagram for the model is shown. It is based on the system description in chapter 2. Endogenously modelled are: the amount of trips all people in a zone make on an average day, the mode choice of these people, the amount of car trips made in a peak hour, the capacity changes due to automated vehicle, the travel times of cars and the amount of vehicle loss hours of cars in peak hours.

The capacity and fuel economy is different for the two development paths for automated vehicles. The value of time changes in relation to normal vehicles, but is not different in the two paths. Exogenously modelled are the change travel time of the train, the growth of population, the introduction of automated vehicles, the number of vehicles, changes in public transport and car costs and economic growth. The choices about what is modelled endogenously or exogenously is made upon the system description based upon Milakis et al. (2015), Snelder et al. (2015) and Gucwa (2014) and is explained in chapter 2.
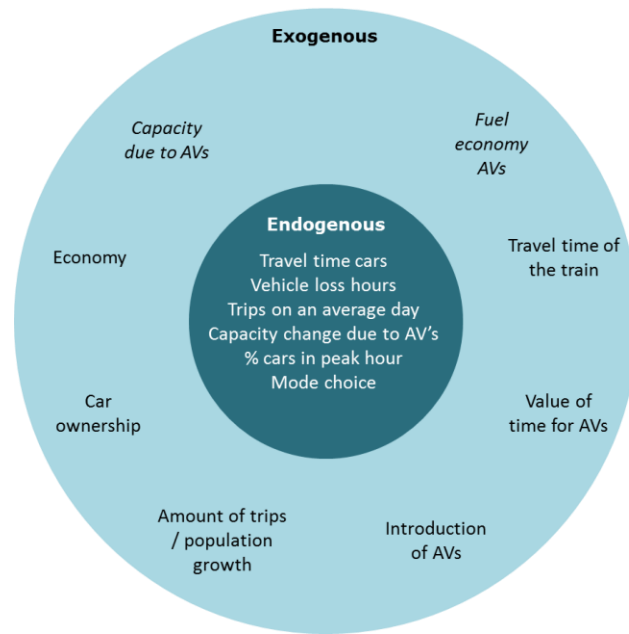
figure 4-1: This bulls-eye diagram shows which factors are endogenously modelled (in feedback loops, changed per time step) and exogenously modelled (differ over time, but are not in feedback loops). In *italics* are exogenous variable that differ in the cooperative and the autonomous development path. AVs is short for automated vehicles.

The 4 steps of the model, with feedback

The SD-model is based upon a traditional 4-step model (McNally 2000), or better, 5-step-model, as also the time of day choice is taken into account. The first and second step of the 5-step-model, trip distribution and generation are simplified to a constant OD pattern. This is used as starting point for the model. This is roughly the same structure as is used in the ScenarioExplorer (1999d). A short overview of the model can be seen in figure 4-2.

The 4 steps of the model

| How many trips are made from where to where? | Which mode is chosen by the travelers? | How many trips are in peak hours? | How long does the trip take? |
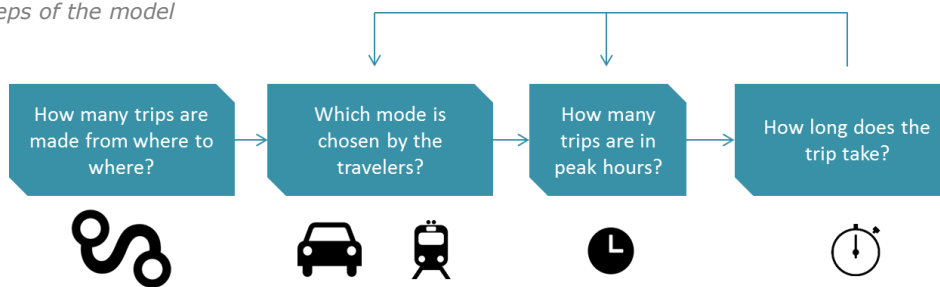
figure 4-2: The model consists of four steps. 1) By extrapolating the base year the amount of trips for coming years are calculated. 2) These trips are divided over the modes based on logit functions. 3) Next are the trips made in the peak hours calculated based upon logit functions. 4) Via a speed-flow curve the travel time of a trip is calculated.

In the first step of the model (trip generation and distribution) the base year origin-destination matrix is extrapolated based on demographics. Secondly, based upon simple utility functions in a logit model, a mode choice is made. For all trips made by car it is calculated how many of the trips are made during peak hours. The amount of trips made during peak hours is used to calculate the travel time via a speed-flow curve. These travel times are fed back with a delay of half a year, as people do not directly change modes after one longer or shorter trip. This perceived car travel time is

fed back to the mode choice and the peak hour choice. So, if the automation of vehicles leads to higher average speeds in the peak hours, the mode car gets more favourable due to higher utilities.

The Netherlands is aggregated into 6 zones, which lead to 42 OD-relations
System Dynamics is a strongly aggregated approach, therefore the Netherlands is split up in only 6 zones. More zones might be preferable, but we use the same approach as the ScenarioExplorer. This makes checks easy and gives the possibility to take over parameters from the ScenarioExplorer. These 6 zones make an origin-destination matrix of 36 cells. The zones are:
- Large cities in the Randstad (LCR)
- Satellite towns of large cities in the Randstad (ST-LCR)
- Cities in the Randstad (CR)
- Rest of the Randstad (RR) or Rural areas of the Randstad
- Cities in the rest of the Netherlands (CRN)
- Rest Netherlands (RN) or Rural areas of the Netherlands

The exact definitions of the zones and a list of all municipalities per zone can be found in Appendix B.
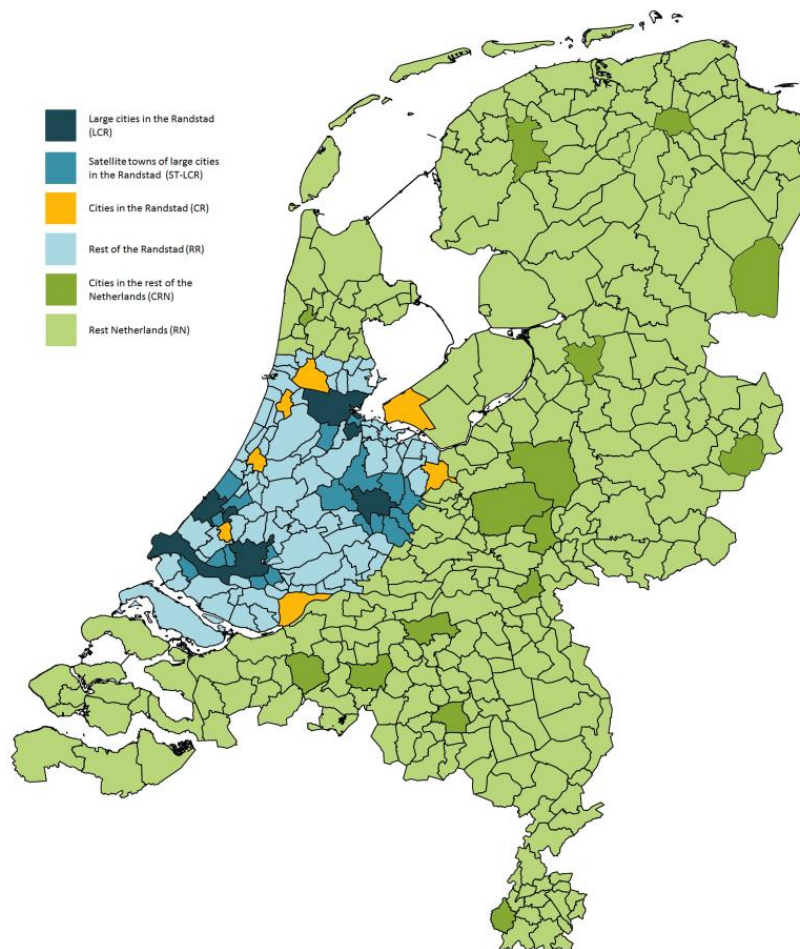
The Netherlands split up in 6 zones

figure 4-3: The Netherlands is split-up into 6 zones. Every municipality is assigned to a zone. Appendix B shows which municipality (definitions of January 2015) is assigned to which zone.

Besides these 36 relations, some extra relations are needed. These 'shadow cells', as they are called (Heyma et al. 1999d), are used to make a difference between local traffic and traffic between cities. Therefore, we added extra zones:

- Other large city in the Randstad (OLCR)
- Other satellite towns of large cities in the Randstad (OST-LCR)
- Other cities in the Randstad (OCR)
- Other cities in the rest of the Netherlands (OCRN)

In this way trips in Amsterdam (inner-city) are separated from trips from Amsterdam to Rotterdam (from city to city). This leads to an origin destination matrix which has the form of table 4-1, with 6*6+6 = 42 cells. As there is no interaction between shadow cells they are only added as column in the OD-matrix.

table 4-1: The empty form of the OD-matrix. The numbers in the table are the numbers corresponding to the relation. On the left side of the matrix are traditional OD cells (1-36), on the right are the shadow relations (37-42). The grey cells are the 4 relations that will be investigated in this research.

	LCR	ST-LCR	CR	RR	CRN	RN	OLCR	OST-LCR	OCR	OCRN
LCR	1	2	3	4	5	6	37	38		
ST-LCR	7	8	9	10	11	12	39	40		
CR	13	14	15	16	17	18			41	
RR	19	20	21	22	23	24				
CRN	25	26	27	28	29	30				42
RN	31	32	33	34	35	36				

Just as in the ScenarioExplorer, four categories are defined: urban roads, rural roads, provincial roads and highways. With this distinction impacts of automated vehicles can be specified per road type. Per road type the free-flow speeds are also the same. An overview of the road types per relation is shown in table 4-2.

table 4-2: Road type per origin-destination relation. The trips are categorised per road type where most time is spend on. A are urban roads, B are rural roads, C are provincial roads, D are highways.

	LCR	ST-LCR	CR	RR	CRN	RN	OLCR	OST-LCR	OCR	OCRN
LCR	A	A	D	C	D	C	D	D		
ST-LCR	A	A	D	C	D	C	D	D		
CR	D	D	A	C	D	C			D	
RR	C	C	C	B	C	D				
CRN	D	D	D	C	A	C				D
RN	C	C	C	D	C	B				

For this research four relations are tested: 1, 21, 36 and 37
The ScenarioExplorer runs the model for all 42 origin-destination relations simultaneous. The SD-model is built for the same 42 relations, but is only simulated for 4 characteristic relations. This is

done to limit the amount of work which has to be done. The four relations are chosen such that from each of the road types one relation is present.

The relations which are chosen are:

Zone	Road type	Reason to use
Rest Netherlands to rest Netherlands (36)	B	Because of its magnitude. Between '10-'13 at least 40% of all trips is made on this relation.
Between the 4 large cities (37)	D	This relations is very insightful as it consists of a limited amount of highways, but still has quite some volume. This is also a relation where impacts of automated vehicles are expected.
In the 4 large cities (1)	A	The results of this relation are also easy to interpret as the results cover only 4 cities.
Between a city in the Randstad and the rest of the Randstad (21)	C	The ScenarioExplorer defines 4 types of relations, of each type one relation is chosen. The relation *provincial roads* is missing, 21 is such a relation. The other provincial relations are all from or to *Rest Netherlands*, which is already present in relation 36.

To limit the amount of work only simulations are done for these four relations. Nonetheless, for all 42 relations the input parameters are determined. This makes that in the future for these relations the simulations easily can be performed. What is not done for all relations is the calibration of the assignment, tests and checks and of course, the simulation[13].

4.2. Step 1: Trip generation

The base year of the model is 2013. Input data for the model is gathered from the mobility survey OViN (CBS 2014). The trips of 2013 year are extrapolated based on demographic forecasts until 2050. The SD- model makes no use of user or age classes, the only distinction in persons which is made are where they live (the 6 zones) and the availability of a car.
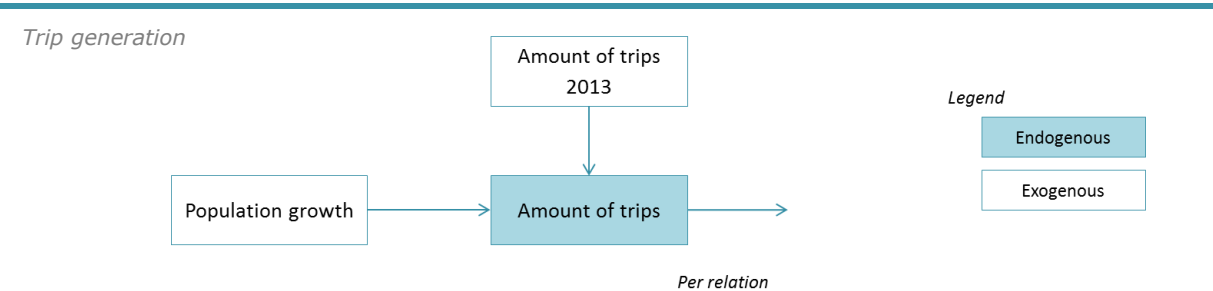
figure 4-4: The number of trips per year is calculated by extrapolating the number of trips of 2013 based on population growth. Other factors are not taken into account.

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[13] The calibration of the mode choice, time of day choice and the input data are generated for all zones. The free-flow speed and capacities per zone are not calibrated. The ScenarioExplorer uses the same free-flow speeds per trip type (all 4 trip types are used), but this is disputed by this research as OViN indicates very different average speeds (max difference 22 km/u) which is probably too large to have one free-flow speed. Most exogenous changes are also available for all zones.

Trip generation and distribution based on extrapolation

In a traditional four step model the first two steps generate trips and distribute these. In this model these two steps are simplified and combined into a single step. The number of trips are extrapolated based on demographic forecasts of PBL (2013). The only aspect taken into account is the demographic growth, which directly correlates to the number of trips[14]. So, 1% extra people in a zone, leads to 1% extra trips. Other demographic or social aspects such as an ageing society or change in labour force are not taken into account. These impacts can nevertheless be significant (PBL 2013), but taking these factors into account would make the model much more heavy and complicated. As the focus of the model is to research the impacts of automated vehicles, these factors are left out of the current research.

The growth figures of PBL (demographic developments 2010-2040) are converted into growth figures per zone. As trips are present per OD-relation and growth figures are per zone, the average of two zones is taken as the growth for an OD-relation.

OViN is used as data source for the number of trips

The OViN survey is used as the data source for the base year. 2013 is chosen as base year. OViN data is gathered via a questionnaire of the Central Bureau of Statistics of the Netherlands (Cbs 2011). Data from questionnaires has downsides, as it is data reported by the travellers themselves, which can contain biases and errors. The CBS filters and checks the data, but still the data is not perfect. There are two other options, which are less favourable than using OViN as base. Count data from the roads or floating car data presents real trips made, but are not available for all modes and all regions of the Netherlands, and cannot be aggregated in zones as origins and destinations cannot be traced back. Second option is to use modelled data, such as outputs of the LMS. An advantage of LMS data is that the outcomes could be easier to compare with the study of Snelder et al. (2015). Downside is that the LMS presents simulated data based upon MON data (a predecessor of OViN), so older survey data than is available right now would be used.

Processing of the data

The data OViN shows travel patterns on a detailed level. The trip data is first aggregated per zone and then again aggregated according to the 42 OD relations and the different modes. In order to get data for an average working day, the weekends and vacations are filtered out. The total number of trips between 2010 until 2013 show smooth and logical patterns. However, some of the figures per zone show large variations in the number of trips, especially the small zones. More on the quality of the OViN data is explained in textbox 1, in the next section.

In order to check if the zone and mode definitions are used correctly, the outcomes are compared with the ScenarioExplorer base matrix. The base year of the ScenarioExplorer is 1990 (Heyma et al. 1999a, p.42). The script used to translate OViN data into a model input is used on MON data of 1990 (the OViN of 1990). The two show great overlap and only differ 0.4%-point of the total amount of

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[14]The model only makes a distinction in where people live and if they have a drivers licence and a car in their household. So, for the model a wealthy retired man with 3 cars living in Amsterdam-Zuid, is the same person as 18 year old in de Schilderswijk in Den Haag who just got his driver's licence whose parents have a car. They both have the same average trip generation and distribution pattern.

trips on average per zone. As the ScenarioExplorer does not give full insight in how the data is processed a 100% match cannot be reached.

Another aspect which shows that the data processing works is that the 1990, 2010,2011,2012 and 2013 matrix are almost symmetrical. Corresponding cells differ 0,03% point at maximum. More explanation on the data processing is given in Appendix A: Processing of OViN and MON data.

4.3. Step 2: Mode choice

To calculate how many people travel with a certain mode a utility based mode choice is performed. The people making trips are divided into trips where a car is available and where no car is available. The utility functions are calibrated based on OViN data of 2010-2013.
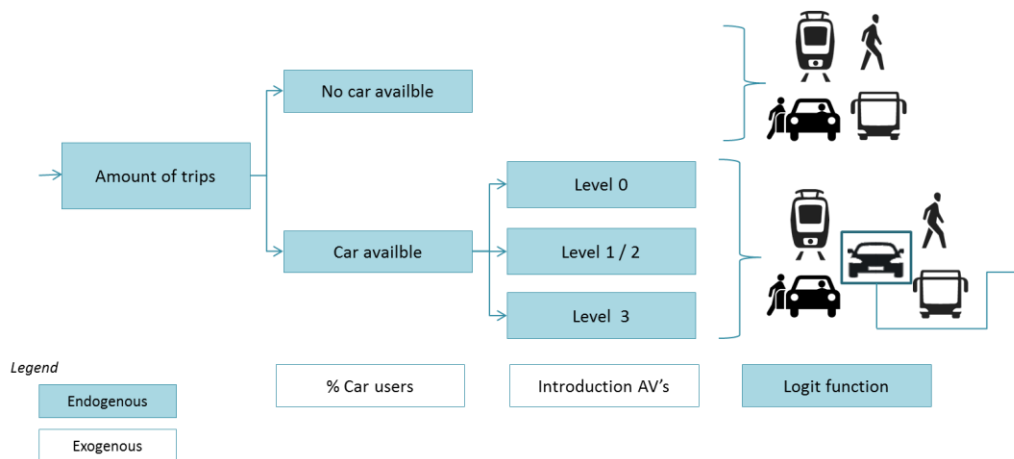

figure 4-5: Two separate mode choices are made. One for trips where no car is available and one for where a car is available. The 'car available' trips are split per level and distributed over the modes via a logit function. The same is done with the 'no car available' trips. This makes a total of 4 different mode choices.

Modes available: car, passengers, train, BTM and slow modes
The model districts 5 different modes: car, car passengers, train, BTM and slow modes. If multimodal trips are made people are categorised per main mode (defined by OViN, where most distance is travelled with).

In the model the trips people make are dived into two groups: trips where a car is available and where no car is available. Availability of a car is defined in the same way as in the LMS (Willigers & de Bok 2011): *people who have a drivers licence (every car should have one driver) and a car in their household*. The percentage of people having a car available for a trip is variable over the years. Automated vehicles can have an effect on car sharing, however, it is assumed that this feedback loop is non-existent for early forms of automated vehicles. For level 4 and 5 this will exist. This does not mean there will not be a rise in car sharing until level 4 hits the market, but not *as an effect* of level 3 automation. Section 0 elaborates on this topic.

The people who have a car available for their trip are again divided into three categories: a level 0 vehicle available (current vehicles), a level 1 & 2 vehicle available, or level a 3 vehicle available. The percentage of vehicles from the different levels is given exogenously. The outcomes of the research of Nieuwenhuijsen (2015) are used. Chapter 5.2 discusses why and how this research is used. After this categorisation in level 0, level 1 & 2 and level 3 availability a distribution is made over car, car passenger, train, BTM and slow modes by a logit. The people who have no car available can choose between the remaining four modes. This choice is also made based upon a logit.

Logit based on travel time costs, distance costs and constant costs
The 4 groups (no car, level 0, level 1 & 2 and 3) have their own discrete choice model. Each of the alternatives has its own utility function. In all car availability functions the non-car alternatives have the same utility functions. This means that for level 1 & 2 owners and level 3 owners the train has the same utility.

The distribution between the alternatives is made via a simple logit function, with three aspects: the costs of the travelled time, the distance dependent costs and a mode specific constant. This is the same set-up as the ScenarioExplorer (1999c) uses. A few factors are somewhat simplified. The parking costs, fixed costs and preference are in one constant, instead of in different constants. Besides that, all people have the same perception of costs and value of time. Equations 1 and 2 here below show the utility functions. These functions are updated every time step of the model.

$$V_{m,r} = -\mu_m \left(TT_{m,r} * VoT_m + Var_{m,r} * d_{m,r} + C_{m,r} \right) \qquad (1)$$

$$T_{m,r} = P_r \frac{e^{V_{m,r}}}{e^{\sum V_{m,r}}} \qquad (2)$$

Where:

V	=	Utility [-]	VoT	=	Value of time [€/hour]
μ	=	Scale factor [1/€]	C	=	Constant [€]
TT	=	Travel time [hour]	d	=	Distance [km]
Var	=	Variable costs [€/km]	T	=	Trips [#]
P	=	Production [# trips]			

m means the value differs per mode, r means the value differs per relation

Parameter	Source of the values	
Value of time (VoT)	*Literature*	The value of time figures are taken over from KiM research. The average values per mode are used (KiM 2013, pp.22–23). For slow modes KiM does not state value of time, therefore the figure for car drivers is used.
Distance (d), travel time (TT) and production (P)	*OViN '10-'13*	These three figures are derived from the OViN research of 2010-2013 (CBS 2014). This means that the figures are reported travel times and reported distances. As in small zones variations are high the sum of the 4 years is used. Appendix A explains how these figures are derived from OViN.

Variable costs (Var)	*Literature*	The variable costs are hard to find in literature. Therefore an old report is used (AGV 1994, p.40). The units are converted from guilders into euro's and corrected for inflation (IISG 2015).
Constant (C) **Scale** **parameter (μ)**	*Estimated based on OViN '10-'13*	The 210 (42 OD relations * 5 modes) constants and 5 scale factors are estimated from OViN '10-'13. The four years are summed as in small zones there is high variation in the data. Via a least square method and the Frontline-solver plug-in in Excel the parameters are fit to the sum of the trips of the four years.
		The car trips (level 0, 1&2 and 3) all use the same constants and scale factors, the differences are in the value of time and variable costs. In trips where cars are not available different constants and scale parameters are fit and used.

The number of trips for passengers, BTM, train and slow modes are not used in next calculations, but form an output of the model. The number of trips for cars is used in the next steps: the time of day choice and assignment. Over time the public transport and car costs (*Var* and *C*) and train travel times (TT) are updated based upon governmental policies and forecasts (Ministerie van Infrastructuur en Milieu 2015; Mansveld 2014).

Limitations of the mode choice
In System Dynamics the use of logit functions is rarely found in literature. Normally stocks and flows are used. If a stock and flows approach was used, the amount of trips per mode would probably be modelled as a stock and changes in mode choice as flows between the stocks. Input data for these kind of structures are rarely found in literature, therefore it is not used.

Another point of discussion is the nature of discrete choice models. A discrete choice function describes a choice between alternatives. However, the choices that are made are no real alternatives. Due to aggregation all trips per mode are the same (no different purposes, one average distance). If people change modes they automatically end up in another average distance category, as the average trips of a train can be longer or shorter than one of a car. This effect can lead to small errors in the outcomes.

4.4. Step 3: Time of day choice model

A logit model is used for the time of day choice. The model has 2 alternatives: driving during peak hours and driving outside peak (off-peak). The logit model uses the value of time, the travel time in and off-peak and a constant. The constants and travel times are estimated based on OViN data from 2010-2013.
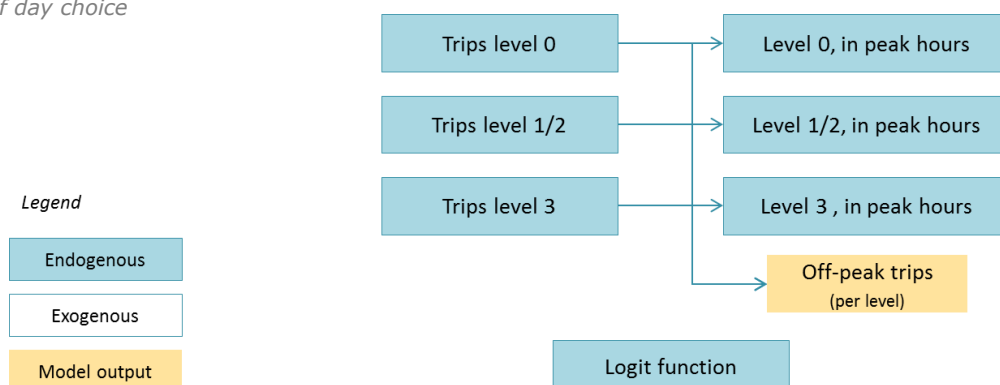
figure 4-6: Per level of automation the number of trips during peak hours are calculated. This is done based on logit functions.

Automated vehicles influence only peak hour traffic
The peak hours are the only hours the Dutch road network is at its capacity and congestion arises. Assumed is that this stays the same when level 3 automated vehicles are introduced. Therefore the assignment is only performed for traffic during peak hours. The ScenarioExplorer uses a constant factor of 7,35%[15] (Heyma et al. 1999d) of traffic which drives in an average peak hour. As automated vehicles might influence the number of trips during peak (Snelder et al. 2015) a simple binary logit

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[15] The factor is the same for each relation. The ScenarioExplorer documentation does not explain how this factor is calculated or how it is derived.

choice model is used in this research. It is assumed that the travel time and a preference for the peak are the only factors influencing the utility for the peak.

In this study a peak hour trip is defined as follows: *every trip in which at least a part of the trip is made between 7:00 and 9:00 or 16:00 and 18:00*. Exploration of OViN data from 2010 until 2013 shows that the percentage of traffic in a peak hour trips differs from 7% until 20% per relation. As the differences are large, each relation has a different utility function and a different constant. The same scaling factor for the sensitivity is used for all functions. The utility is calculated as follows:

$$V_{p,r} = -\mu \, (TT_{p,r} * VoT + C_r) \qquad\qquad (3)$$

Where:

V	=	*Utility [-]*	VoT	=	*Value of time [€/hour]*
μ	=	*Scale factor [1/€]*	C	=	*Constant[16] [€]*
TT	=	*Travel time [hour]*			

$_p$ means the value differs in peak and off-peak, $_r$ means the value differs per relation

Calibration of the constant (C) and scale factor (μ) in the model
The travel times during peak hours are gathered from OViN. The off-peak values can also be gathered from OViN data. However, as off-peak a different type of trips are made than during peak hours (sometimes with lower average speeds) the free-flow speeds of the relation are used. Next chapter discusses how the free-flow speeds are derived.

The years 2010 until 2013 of OViN are used to calibrate the constant and the scale factor. This can be done with values which fit on all years. This leads to a result of only 4%-miscalculated trips (in-sample performance). This is quite good, however, to be consistent with the mode choice, the four years are used summed to calibrate the constants and the scale factors (0% miscalculated trips, in-sample performance).

The constant includes the preference for the peak. The μ covers the sensitivity for changes, the closer to zero, the less sensitive. A least square estimator in Excel has calculated the 42 constants and the μ on the basis of the trips made during peak hours of the 4 years ('10-'13).

4.5. Step 4: Assignment

In the assignment, the travel time for cars is calculated based on the flows during peak hours for the three car groups. This is done by combining the number of trips from the different cars groups (level 0, 1 & 2 and 3) and the trucks on one relation. Due to the lack of an explicit network an overlap factor needs to be used, as two different relations interact on one physical road. Via a speed-flow function the travel times are calculated. This travel time is fed back to the mode choice and time of day choice to update the utilities.

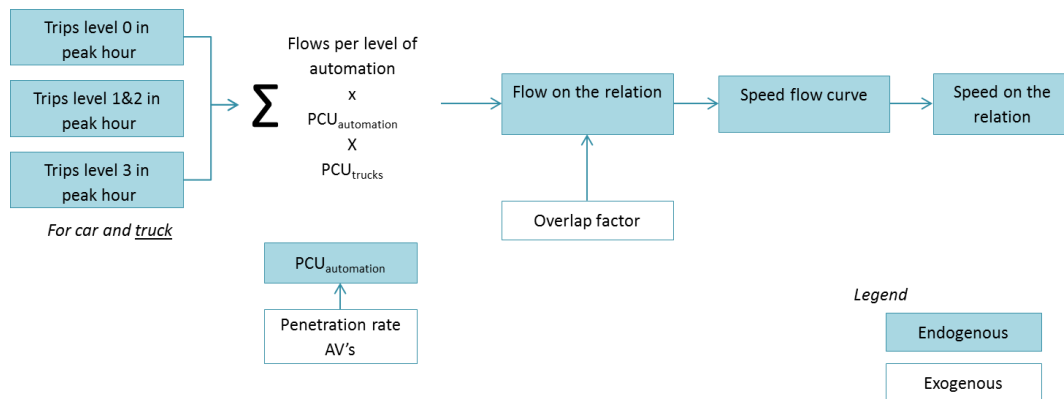[16] For the off-peak trips the value of the constant is zero

figure 4-7: The flow is calculated by summing up the flows per level for trucks and cars. These flows are multiplied by an optional PCU factor for trucks and another for automation. The outcomes are multiplied by the overlap factor to get the flow on the relation. Via the speed-flow curve the speed is calculated based on the flow and capacity.

Automated vehicles do not influence capacity, but influence the flow

Due to automation the capacity of a road can change. Most studies indicate higher capacities, but also lower capacities could be an effect (Snelder et al. 2015; Hoogendoorn et al. 2014). In most studies the capacity of a road is changed in order to simulate these effects (Snelder et al. 2015; Gucwa 2014). In this research however, a different approach is used. Not the capacity, but the flow of automated vehicles is changed. This is a similar approach as using a PCU[17] for trucks. Where a normal car 'consumes' one unit of capacity, this amount is made variable for automated vehicles. An automated vehicle can 'consume' therefore only 0,8 units of the capacity. This is called the *PCU* factor for automation. For normal cars this factor is 1, for automated vehicles this can be somewhat more or less than one. Using a PCU value has several advantages:

- The speed-flow curve and capacity of a road can stay the same as in current simulations.
- Mixed traffic can more easily and explicitly taken into account. Mixed can mean different levels or trucks and cars, but in enables also that cooperative and autonomous vehicles can be mixed.
- Not for all penetration rates of automated vehicles new microscopic simulations have to be done, as this factor makes it easy relate impacts to penetration rates.
- It makes capacity impacts of automated vehicles more explicit, insightful and therefore discussions on the factors are more easily to have.

The next chapter (5.4) discusses the values for the *PCU*.

Different relations using the same road: overlap factor

Performing an assignment in System Dynamics models is complicated, as an explicit network is hard to model. Complicating aspect is that multiple origin-destination relations interact with each other in a network. To give an example: traffic from Den Haag to Utrecht (Large Randstad city to Large Randstad city), interacts with traffic from Gouda to Nieuwegein (Other city Randstad to Satellite town large city). This traffic uses the same roads and therefore 'consumes' the same capacity. In

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[17] PCU is a passenger car unit. As heavy goods vehicles and passenger cars both use a different space on the road (different length, different distance to predecessor), capacities are expressed in PCU values. Cars consume one PCU, trucks mostly between 1,8 and 2. In this way the capacity of a road stays the same with different shares of cars.

normal traffic models the relations interact with each other in a network, which is very hard to model in System Dynamics. The ScenarioExplorer (Heyma et al. 1999d) has found a way to work around this: the overlap factor.

The *flow in a peak hour* of a relation is multiplied by the *overlap factor*. This factor represents the amount of other traffic on the roads of that relation. Trips between the four large cities of the Randstad use the same roads as from satellite town to satellite town. If on the roads 50% is between large cities and 50% between satellite towns the overlap factor for the trips between large cities is 2. In the ScenarioExplorer this factor is made dynamic. This means that if a related relation grows the investigated relation is influenced. As in this research not all relations are investigated a static overlap factor is used. The overlap factor is derived from the source code from the ScenarioExplorer (Heyma et al. 1999b) and modified to make it static.

Using the overlap factor is full of assumptions
The use of the overlap factor has three main assumptions. These are also explained by Heyma et al. (1999b).

The overlap factors found by the ScenarioExplorer in 1999 are a good representation for the overlap factors the coming years.
The developers of the ScenarioExplorer have made an "manual and rough estimation" (Heyma et al. 1999d, p.21) of the factors and suggest this can be improved with an analytical model. This, however, is never done and is a very time consuming effort that improves the model only slightly. Therefore is assumed that the overlap factor from 1999 until 2050 does not change. This assumption holds as the core characteristics of the Dutch road network are already older than 1999. In addition, if new roads are build (for instance the A4 between Delft and Schiedam) the same OD-shares will drive on that road, which means that the overlap factor can stay the same.

Automation influences all zones in the same way
If car traffic in different zones is influenced the same way the overlap factor stays the same. As automated vehicles are introduced at the same time, the impacts will roughly and relatively be the same. Small changes can occur as automated vehicles have larger impacts in some zones than in others.

No change in route choice over the time
No change in overlap factors assumes that if new routes arise, the interacting relations also make use of this road. "As long as aggregated networks links are used, will the number of alternative routes stay limited, and is this assumption justifiable"[18](Heyma et al. 1999d, p.21).

Assignment via a speed-flow curve
The assignment is made with a BPR function[19], which is a particular form of a speed-flow function. The ScenarioExplorer (Heyma et al. 1999d, p.22) makes use of the same approach. The input of the

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[18] Authors translation from Dutch: "Zolang van geaggregeerde hoofdnetwerken en hoofdverbindingen wordt uitgegaan, zal het aantal alternatieve routes beperkt blijven en lijkt deze aanname gerechtvaardigd."

function is the volume corrected by the PCU's and the overlap factor. This function calculates with the capacity and free-flow speed the average speed of cars during peak hour on the relation.

We use the same speed-flow curve as Heyma et al. use. The formula for the assignment function for one relation is:

$$S(t) = \frac{S_0}{1 + b * IC^4} \qquad (4)$$

$$IC = \frac{(\sum(Pas\ int_l * PCU_l) + (HGV\ int * PCU_l * PCU_t) * OF}{Cap} \qquad (5)$$

Where:

S_0	=	Free-flow speed [km/hour]	b	=	Urbanisation factor [-]
$S(t)$	=	Average speed on the relation [km/hour]	IC	=	Intensity or flow – capacity ratio [-]
$Pas\ int_l$	=	Amount of trips per level [cars/hour]	$HGV\ int$	=	Amount of trips of trucks [trucks/hour]
PCU_l	=	Passenger car unit for automation [cars/veh]	PCU_t	=	Passenger car unit for trucks [trucks/veh]
Cap	=	Capacity of the relation [veh/hour]	OF	=	Overlap Factor

l means the value differs per level of automation (SAE)

Capacity, free-flow speed and urbanisation factor

As discussed in 4.1 there are four road types: urban roads, rural roads, provincial roads, and highways. For each of these road types a free-flow speed (S_0) and urbanisation factor (b) are defined. The capacity (cap) differs per relation. The three factors influence the speed-flow (SF) curve in a different way, in figure 4-8 is shown how.

The free-flow speed (S_0) can be derived in two ways, both leading to a different result. The first way is to use the same values as in the ScenarioExplorer. The second is to derive the values from the average speeds of nightly trips from OViN '10-'13. Both methods are compared. Sometimes the ScenarioExplorer values seem more logical, sometimes the OViN nightly travel times. Therefore an assumption[20] is made, based on the ScenarioExplorer values and the OViN nightly data compared to the travel times during the day. The values used for the four investigated relations can be found in table 4-3.

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[19] BPR stands for Bureau of Public Roads (of the US), they defined a simple function to describe the relation between flows, travel times and capacities on a road.

[20] In this study 4 characteristic relations are tested (relation 1, 21, 36 and 37). The assumptions on the free-flow speed are mainly made based on these four relations. As the speeds during day in the four categories still differ a lot (max 22 km/h in one category) a general free-flow speed cannot be derived per road type. Doing this would lead to very high impacts of automated vehicles on some relations, and very low on others. The assumptions on the speeds are fine for the largest share of the relations, for the other relations other values are needed. Especially in the C and D relation is the variation high. For future research it might be good to use more or different categories as the variation in speeds in a category is high.
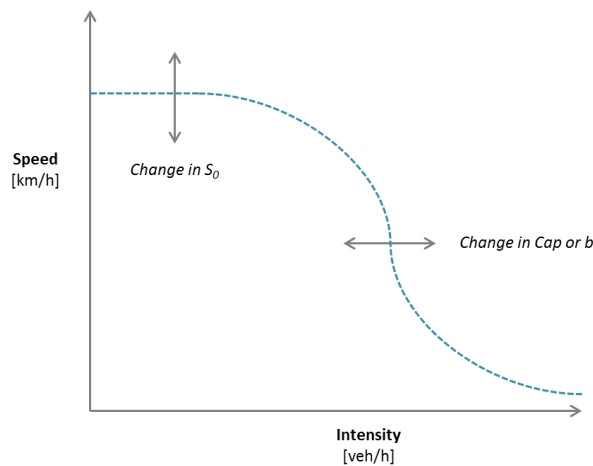
Speed-flow curve and how different factors influence it

figure 4-8: Speed-flow curve and how the capacity (cap), urbanisation factor (b) and the free-flow speed (S_0) influence the curve.

Calibration of the capacity

The urbanisation factor (b) and the capacity (cap) influence the shape of the speed-flow curve in the same way. The urbanisation factor is directly taken over from the ScenarioExplorer. The capacity of a relation, the network between the zones, is hard to determine as this consist of numerous roads. The ScenarioExplorer does not explain how they determine capacities and do not state values for capacities in their documentation. In the available part of the source code the capacities are also unfindable. Therefore, a different approach is needed. As the form of the speed-flow curve is known, and the free-flow speed, with one other point the curve is fully determined. A point on the graph that is known is the speed and corresponding volume in 2013 on the relation. With this speed the capacity is calibrated.

By using the approach, the capacity has no one-on-one relation with the real world capacity. It is calibrated with the model and OViN data. Attempts are done to calculate the capacity on a relation (for instance between large cities in the Randstad), by summing up all the highways lanes and multiplying them with 2000 veh/h per lane. This approach seems logical, but leads to way too high average speeds. This is probably because other factors as the start and end of the trip in urban areas, weaving areas, internal overlap, spillback from other routes, detours, searching for parking spots also influence the travel time.

What is obtained with the calibration is the capacity of a network on the relation. The capacity of for instance relation 37 is the capacity of the network between the four large cities of the Randstad. The capacities, urbanisation factors and free-flow speed of the four characteristic relations are shown in table 4-3.

table 4-3: Free-flow speed, urbanisation factor and the estimated capacity of the network for the four relations.

	Road type	b [-]	S_0 [km/h]	Capacity [veh/h]	Overlap factor [-]
(1)	Urban roads (A)	3	35	315000	1.64
(21)	Provincial roads (C)	2	50	324000	10.92
(36)	Rural roads (B)	3	50	1838000	1.16
(37)	Highways (D)	1	65	118240	9.27

Feedback loops

For the mode choice and the departure time choice the travel time is needed as an input. Every time step (a week) the travel time is fed back from the assignment to the mode and time of day choice. In the feedback a 'first order information delay', or 'first order exponential smoothing' is used (Sterman 2000). A delay of half a year is used in the exponential smoothing. This means that every week the weighted travel times of the past half year together form the perceived travel time. The initial value in the delay is the travel speed from OViN on the relation. As automated vehicles are not expected to have impact in off-peak hours the travel time off-peak is set as the free-flow speed.

Feedback in the model   *Averages of a half year are fed back every week*
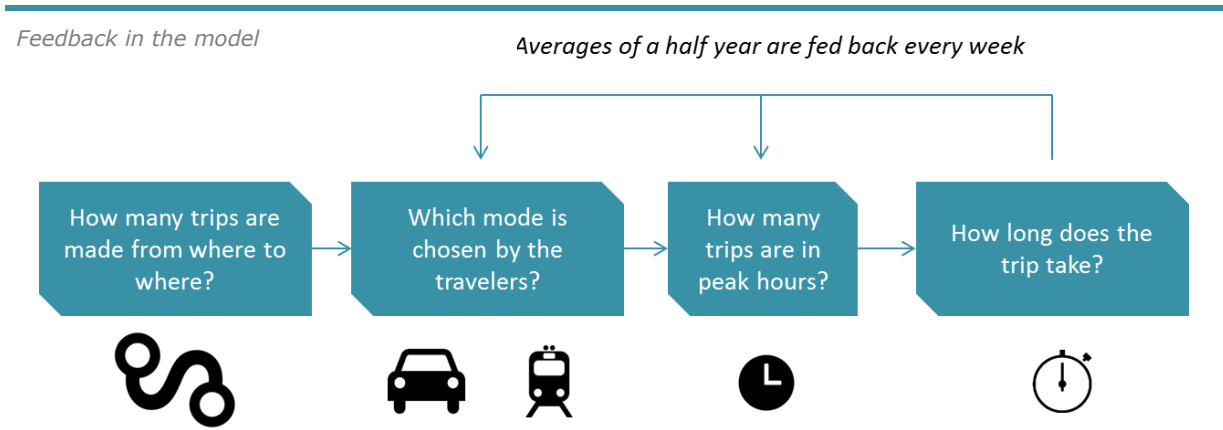
figure 4-9: The four steps of the model and the feedback between them. The travel time is fed back to the time of day and mode choice.

4.6. Trucks

In the model heavy goods vehicles are taken into account as they have a significant impact on the transportation system. The number of trucks traveling in the base year is calculated from amount of the passenger car trips in 2013, this number is extrapolated over the years based on information the LMS also uses. The automation of trucks is taken into account the same way as is done with passenger cars.

Trucks

figure 4-10: The mode choice and time of day choice are fixed for trucks. Automation of the fleet in taken into account the same way as is done with cars.

Fixed values are used for the mode choice and time of day choice for trucks

Heavy goods vehicles influence the travel time of passenger cars, and vice versa. The trips of heavy goods vehicles are also taken into account in the model, however, more si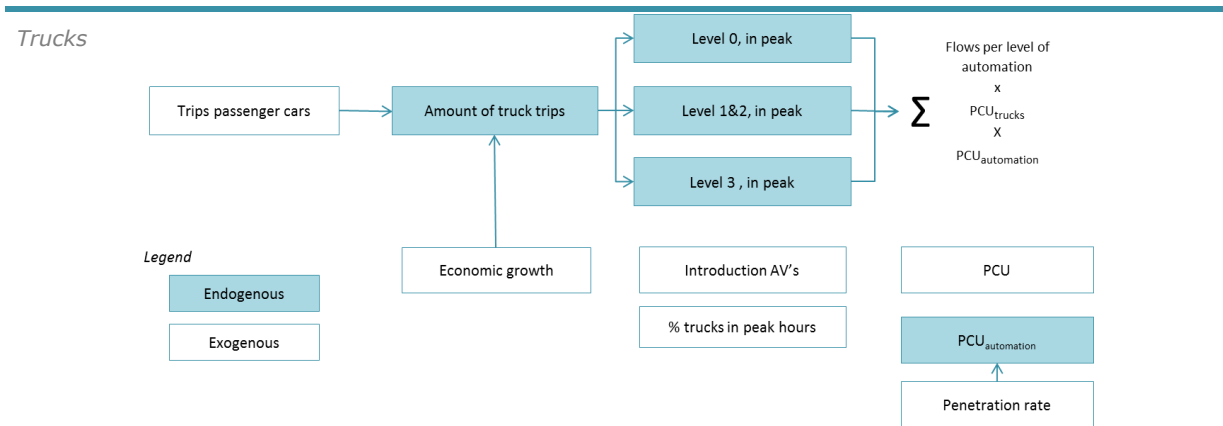mplistic. The same 42 relations are used, but the mode and time of day choice are set as fixed percentages. The amount of trucks on a road is 8% of the passenger cars (Goudappel 2014; NDW 2016). This value is set for the base year. This is extrapolated based upon the same figures as the LMS uses. A fixed percentage of 6% is travel during peak hours. Both the mode and time of day choice percentages are derived from INWEVA data (NDW 2016).

There are other possible methods to determine the amount of truck trips. However, these are quite cumbersome. The CBS survey for goods can be used (the OViN for goods), however, they use overlapping zones and present the number of goods instead of the number of trips. Empty trips, different driving routes and different truck sizes make estimating the number of trips almost impossible. Using data from LMS OD matrices via BasGoed is also taken in consideration, but lead to lots of calculation work for only a small improvement of the model. Therefore the simple approach of using 8% of the normal traffic is used. This figure is used for all relations. That automation of trucks can lead to more trucks is not taken into account.

The automation of heavy goods vehicles

Besides passenger cars also heavy goods vehicles can be equipped with technology to automate the vehicle. The percentage of automated trucks is the same as with passenger cars. So, three categories are made: level 0, level 1/2 and level 3. As for trucks only the assignment is made. Impacts on value of time or fuel economy are not taken into account. The only aspect which is used is the impact on capacity. This is done in a similar way as with passenger cars: automated trucks 'consume' less capacity than a non-automated truck. Just as with the passenger cars this is overcome by taking an *Passenger Car Unit* (PCU) for automation into account.

Heavy goods vehicles already 'consume' more capacity than normal vehicles, so there are two PCU factors in the formula. The PCU value is set at 1,9, which is also the value in the LMS (Rijkswaterstaat 2012) and the outcome of microsimulation studies[21] (Minderhoud 2011). The volume of trucks is calculated via the following formula:

$$HGV\ Int = \sum HGVInt_l * PCU_l * PCU \qquad (6)$$

Where:

HGV int =	*Intensity or flow of trucks [veh/hour]*	*HGV int$_l$=*	*Intensity or flow of trucks per level [trucks/hour]*
PCU$_l$ =	*Passenger car unit for automation [1/veh]*	*PCU =*	*Passenger car units [-]*

l means the value differs per level of automation (SAE)

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[21] Minderhoud states that when capacity is reached values between 1,9 and 2,1 can be used. Per extra percentage trucks the CPU value rises with 0.01. As the number of trucks only differs mildly this elasticity is not taken into account.

4.7. Model set-up for exogenously changing variables

Besides the automation of vehicles also other variables influence mobility in the Netherlands. The SD-model assumes the same growth figures as the LMS. Most inputs are based upon the *starting points document* of the Ministry of Infrastructure and Environment (2015). Information not explained in this document is derived from other governmental documents. Eight factors change exogenously in the model, table 4-4 lists them.

table 4-4: Overview of the exogenous changing parameters per year with their source.

What	Change per year	Source
Population growth	Between 0.1% and 0.4%	PBL (2013)
More car ownership	0.2 %-point extra cars available	LMS assumption (Ministerie van Infrastructuur en Milieu 2015)
Higher PT costs /km	0.5% extra €/km	
Decrease car costs / km	0.7% less €/km	
More trucks	1.4% extra trucks	
Faster trains	0.3 minutes *(between '17 and '30)*	Program High Frequency Rail (Mansveld 2014)
Extra road capacity	Between 0.8% and 1.3% extra	Assumed based upon highway expansion between '14-'17 (Rijksoverheid 2015)
Introduction of Automated vehicles	*Will be discussed in chapter 5.2*	Nieuwenhuijsen (2015)

Population growth

The current version of the LMS is based upon figures from 2006. The SD-model uses updated figures for growths from PBL (2013). In the report they forecast demographic growth from 2010 until 2040. As there are no growth figures for 2050 the same figures for 2050 as for 2040 are used. PBL uses other zone definitions, so a translation has to be made. PBL explains that the whole of the Netherlands grows by 7% until 2040. The cities and neighbouring areas are expected to grow the most (12%) and rural areas only a 2%. In some areas a decrease in population is expected, but these regions are grouped with faster growing areas (in RR) in the SD-model. The average growth weighted to the amount of trips (derived from OViN) comes down to the same 7% as the PBL expects.

table 4-5: The demographic figures of the PBL translated into growth figures per zone for the SD-model.

Zone	Growth 2010-2050	Based upon
LCR (large cities Randstad)	12%	Cities
ST-LCR (satellite towns of large cities)	12%	Cities
CR (cities in the Randstad	12%	Cities
RR (rest of the Randstad)	7%	Average of the Netherlands.
CRN (cities rest Netherlands)	12%	Cities
RN (rest Netherlands)	2%	Only a few percent

The growth of the population is not linear, but to simplify the SD-model it is modelled linear. As the SD-model calculates trips based on 42 relations and not on the 6 zones the average growth of the origin and destination zone are used. For the shadow zones the growth figures of related zones are used.

More car ownership
The car ownership is expected to rise the coming years. The planning bureaus of the ministry assume a growth of 0,2% per year until 2040 (Ministerie van Infrastructuur en Milieu 2015). It is assumed that this trend continues until 2050.

Automated vehicles or for instance car sharing can influence the ownership of cars (KiM 2015). Both factors are not taken into account. The effect of early forms of automated vehicles on car sharing is assumed to be small, and the influence of car ownership is out of scope for this research. Differences per zone are also not taken into account.

Higher public transport costs
In the starting points document (2015) is described that prices of public transport will rise from 2004 until 2030. They explain that the prices in this period will rise with 16% above the consumer index. This makes that 0.5% extra per year. The prices per kilometre per year for the train and BTM rise with the same percentage per year, until 2030.

Lower car costs
Where the costs of the public transport rise, the costs for a car decrease. Fuel, maintenance and cars themselves get cheaper. The LMS assumes the costs per kilometre will drop by 15% the coming 20 years. In the SD-model the assumption is used.

More trucks
The amount of heavy goods vehicles on the road is expected to rise. The LMS expects a quite large growth of 1.4% per year. The same figure is used by the SD-model. No differentiation per zone is made.

More trains
The government has a program to invest in high frequency rail (Mansveld 2014, program high frequency rail). This is not named in the starting point document, but still is taken into account. The investments will not lead to faster trains, but to more trains. This will decrease the waiting time. The average time between trains is expected to decrease from 15 to 7.5 minutes. This means that the average waiting time (half of the time between trains) decreases 3.25 minutes when no one plans a trip. As the program high frequency rail is only introduced at one some relations and passengers time their arrival, the average travel time is expected to drop with 0.3 minutes per year from 2017 until 2030.

New roads built
Extra roads or lanes are directly related to the travel time of cars, therefore changes in the network should be taken into account. As the capacity is very abstract in this research (estimated with the free-flow speed and speed during peak hours), projects related to extra roads are hard to translate to capacity in the model. Extra difficulty is that the capacity in the model is the "bottleneck capacity" of

this relation. Therefore, the percentage by which the bottleneck capacity grows per year is used in the model.

This percentage is derived by comparing the actual amount of *lane kilometres* highway[22] to the plans of the Dutch government. The current road network consists of 16240 lane kilometres highway[23], and from 2013 until 2017 it is expected to grow with 143.4 km per year (Rijksoverheid 2015), which is 0.88% per year. As Rijkswaterstaat is expanding tactically and this standard growth is enlarged with a tactical factor. These factors are shown in table 4-6. These highway estimations are also used for other road types than highways. For these roads there is no or incomplete information. For traffic in cities lower tactical factor are used as there it is sometimes impossible to expand the road network.

table 4-6: The growth of the road network per year consist of the growth and a factor who tactical this is done. As in urban areas infrastructure is dense roads cannot always be enlarged on the ideal places.

Road type	Standard growth [%]	Tactical factor [-]	Growth per year [%]
Urban roads (A)	0.88	0.5	0.44
Rural roads (B)	0.88	1.25	1.1
Provincial roads (C)	0.88	1.25	1.1
Highways (D)	0.88	1.25	1.1

Not taken into account

Besides these 8 changing variables different other aspects can also influence mobility. E-bikes, new cycling paths, traffic management, a different home and working locations or an aging population are all not taken into account. As this model assess the impacts of automated vehicles, the focus is on these developments and not on other changes.

4.8. Software

For the SD-model System Dynamic simulation software is used. The professional edition of Vensim 6.3 is used to create the model. The time step for the model is 0.0625 year. This means that the model has time steps of three weeks. This is the largest time step where no changes in solutions were found. The integration method is set to Euler, as there are discrete elements in the exogenously modelled variables. The whole model is deterministic; this means the model uses no stochastics. Therefore every run of the model with the same settings gives the same outcomes.

The model can do 100 simulations in 2 seconds (Intel i5 with 4GB ram). This makes it that it almost instantaneous input can be changed and exploring becomes very easy. The size of the model and its input sheets vary per type of run but are always less than 500 kb.

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[22] Lane kilometres are the amount of kilometres road times the amount of lanes per road section. 2 kilometres with 3 lanes means 6 lane kilometres. This unit is used because the government expresses themselves in this number on the expansion of the road network.
[23] This number is derived from information from Rijkswaterstaat their e-mail and telephone service. Only main carriageways are used for this calculation. On, off-ramps and connecting roads are not used in this estimation.

5 Automated vehicle model variables

The previous chapter discussed the model structure. This chapter elaborates upon the differences between the two development paths and how they are modelled. The development paths do not differ in structure of the model. The only aspects which are changed for autonomous and cooperative cars are: the value of time, the PCU (capacity) and the fuel economy.

table 5-1: Overview of the diffusion and the 3 aspects which are changed for automated vehicles. Cooperative vehicles have extra benefits above 40% penetration rate as they have the ability to platoon.

	Road type	Autonomous	Cooperative	
		Diffusion of automated vehicles		
All levels		Graph from research Nieuwenhuijsen (2015)		
		Value of time		
Level 0	all	100%		
Level 1 & 2	all	100%		
Level 3	Inner city	100%		
	Rural / provincial	90%		
	Between cities	80%		
		PCU (capacity)		
Level 0	all	1	1	
Level 1 & 2	Inner city	1	1	
	Rural	1	1	
	Provincial	1	1	
	Between cities	1	[0-40%]	1
			[40-100%]	Decrease till 0.95
Level 3	Inner city	0.95	0.95	
	Rural / provincial	1	[0-40%]	1
			[40-100%]	Decrease till 0.95
	Between cities	1	[0-40%]	1
			[40-100%]	Decrease till 0.9
		Fuel economy		
Level 0		1	1	
Level 1 & 2		0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85
Level 3	Inner city	0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85
	Rural & provincial	0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85
	Between cities	0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85

5.1. Not taken into account in the model

Besides these three factors which are taken into account, there are also several effects not taken into account. Literature names lots of other factors which are simulated by automated vehicles. Many effects named in literature start playing a role with level 4 and 5, such as empty trips, drunken driving or kids alone in the car. Especially the literature review of Snelder et al. (2015), the work of Gucwa

(2014) and the work of Litman (2014) state effects which could arise when a fleet is automated. The effects that could arise in level 3, but are not modelled are summed up in this section.

Longer trips

Automated vehicles can lead to longer trips, as people might change houses or working location. This can happen for two reasons: people can work in the vehicles (lower value of time) or due to faster travel times. Both effects can arise for level 3 vehicles. Still, the effects are not modelled as they are hard to model. Almost no literature is available on this topic and the effects are expected to be small. In section 6.4 this assumption is discussed.

Transportation of goods

If trucks are automated, transportation via the road might become more attractive. There are two reasons for that. Firstly, the travel time can be shorter, which probably will have a small effect. Secondly, the tachymeter, which controls how many hours the driver has driven, can stop counting if the driver can do something else while driving. The second can have larger impacts on the travel time of longer trips for trucks. Still, a mode choice for goods is out of scope for this research, but is advised to take into account in future research. The automation of the current fleet is taken into account when the supply is modelled.

Parking

Highly automated vehicles can park themselves, but also for level 3 vehicles new parking options could arise. Designated areas such as a car park can have a drop off zone for level 3 vehicles which can park themselves. This could decrease the parking time drastically. As there is few research on this topic, it is hard to model this aspect. Therefore it is not taken into account

Reliability of a trip

The reliability of trips is named by Snelder et al. (2015). This could go up as more information is present, less congestion arises and searching a parking place gets easier. Therefore car trips might become more attractive. As this topic is hard to model and has relations with many different other variables, it is not taken into account. The impacts are not expected to be high, Snelder et al. also gives this aspect a low priority.

Safety

Fewer accidents can be a positive effect of automation. A welcome side effect is less congestion due to accidents. This effect is hard to quantify for an average day, and therefore not taken into account. Other models like the LMS also do not take this aspect into account. Secondly, due to higher safety other effects could arise: the preference for the car can increase, cars can become smaller (as crumple zones are less needed) or larger (as working in a car gets more convenient). These effects are expected to be small and hard to quantify, and therefore not taken into account.

Infrastructure

Besides the effects on vehicles, also infrastructure can change. More narrow roads or other type of junctions could influence the capacity, however, in mixed traffic these measures will not be taken. A dedicated lane for automated vehicles is also not taken into account as research does not show benefits and the ministry of I&M or Rijkswaterstaat do not state this in their policy notes.

5.2. Diffusion of automated vehicles on the road

On the current roads we see mainly level 0 vehicles, with a small percentage of level 1 and 2. That level 1 and 2 vehicles will be the future, is evident. Almost all new luxury cars have ACC and a form of lane keeping. These functions become more and more available for middle class vehicles. The innovation of higher levels of automation is debatable. Some argue that level 5 vehicles will never make it to market as software will never be able to handle the complex traffic environments in all situations. Whereas other (for instance Google) argue that the human-machine interaction of level 2 and 3 can lead to very unsafe situations[24].

This research takes level 0, 1, 2 and 3 vehicles into account. That level 1 and 2 are sold already. However, the introduction of level 3 vehicles is questionable, but in this research they can also be seen as a first version of automated vehicles where a driver can do something else while driving. This can be level 3, but also an early form of level 4, which is not allowed on all roads. The two development paths, mentioned in the introduction, are based upon research of Timmer and Kool (2014), Wilmink et al (2014), Bhat (2014) and Milakis et al. (2015). The definitions of SAE (2014) are used for the levels. More explanation about the two development paths can be found in the introduction. A definition of each level for the two development paths is presented here below in table 5-2.

table 5-2: For the two development paths (autonomous and cooperative) a definition is presented per level of automation.

	Autonomous	Cooperative
Level 0	Full time operated by a human driver, can be assisted by warning systems *Example: a regular car*	
Level 1	Driver is assisted by a system in the acceleration and deceleration task[25] *Example: adaptive cruise control*	Driver is assisted by a system in the acceleration and deceleration task. The vehicle communicates with other vehicles. *Example: cooperative adaptive cruise control*
Level 2	Driver monitors the environment, but the system can take over the steering and control the speed. The vehicle observes other vehicles. *Example: adaptive cruise control + lane keeping (Tesla model S)*	Driver monitors the environment, but the system can take over the steering and control of the speed. System communicates with other vehicles. *Example: cooperative adaptive cruise control + lane keeping*
Level 3	The system monitors the environment and operates the vehicle. However, the system can ask the driver to take over the wheel. The car only observes to other road users, but does not communicate with them. *Example: the Volvo commercial.*[26]	The system monitors the environment and operates the vehicle. However, the system can ask the driver to take over the wheel. The car observes and communicates with other road users. *Example: the goal of DAVI*

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[24] ANWB and to a lesser extent Rijkswaterstaat question the desirability of level 3 vehicles in the interviews done (see appendix ..), as they see troubles with the human-computer interaction. Drivers would have a lower workload and start doing other things while driving, and will not react in time.

[25] Definition of level 1 is that the driver is assisted in "either steering *or* acceleration/deceleration", this is changed to only acceleration/deceleration. This definition without a choice is needed to create the model. Level 2 is defined as having both.

[26] Commercial is called: *Drive Me -- Autonomous driving pilot project* and can be viewed here: https://www.youtube.com/watch?v=MxGE6FrGj7c

As the levels 1 and 2 only differ in the lateral movement (lane keeping), the same effects are expected for capacities, value of time and fuel consumption. Therefore they are treated as one single group in the model. Snelder et al. (2016) also names the option of simulation level 1 and 2 as one mode.

Percentage of automated vehicles on the road
The diffusion of automated vehicles is an exogenous variable in the model. Academia, car manufacturers and government officials heavily speculate about this topic. In some research expert opinions are used (Milakis et al. 2015; Shladover 2015), others compare it to other vehicle innovations (Litman 2014), but only one research uses a quantitative model to calculate the diffusion of automated vehicles (Nieuwenhuijsen 2015). His model relies on assumptions, but is however underpinned with expert opinions and literature. Unique aspect of this research is that the forecasts are per SAE level, where most studies do not differentiate the type of automated vehicles they mean.

There are two downsides of using the research of Nieuwenhuijsen. The first is that the forecasts of Nieuwenhuijsen's model do not correspondent with percentage of automated vehicles on the roads nowadays. The model presents a too optimistic view for 2015, namely 30% level 2 vehicles, where this is currently less than 1%[27]. To compensate for this effect the outcomes of the model of Nieuwenhuijsen are shifted 10 years in time, as there is enough evidence to trust the curves, but not to trust the starting point.

Second point is that Nieuwenhuijsen's model estimates the percentage of automated vehicles *owned* in the Netherlands and not the percentage of *trips made* with automated vehicles. Litman (2014, p.11) describes that new vehicles drive more kilometres than old vehicles. The first 10 years of the lifespan of a vehicle more double the amount of kilometres is driven than the years after the 10th. This effect can lead to a steeper introduction curve. The effect however, is not taken into account in the model as this would lead to much more complexity because vehicle should be divided in age classes as well. The forecasts of Nieuwenhuijsen are for passenger cars. We use the same introduction graphs for trucks, as there is no other literature available.

5.3. Value of time

The value of time is the opportunity costs for traveling a traveller spends on the journey. Due to automation, time in the vehicle can be spend differently, namely on working or relaxing (Snelder et al. 2015). This phenomenon is called 'travel time-' or 'journey time enrichment' (KiM 2013, p.29; Milakis, van Arem, et al. 2015, p.3).

Level 3 is the only level where the value of time changes
Level 1 and 2 will not have an effect on the value of time as in both development paths the driver has to pay attention while driving. As no other tasks can be performed, the travel time is not enriched. For level 3 vehicle we expect changes in value of time (Milakis, van Arem, et al. 2015), but figures on

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[27] The only level 2 on the Dutch roads is the Tesla model S. In June 2015 only 3.541 of these models are sold in the Netherlands, on a total of 8 million cars on the road.

this topic are scarce. Cyganski et al. (2014) have asked people what they would do in the car if their car had a "highway pilot" (comparable with level 3). Only a few people stated they would work in the car. Most of them would relax. Gardner and Abraham (2007, p.109) state that "Participants tended to neglect the potential for journey time to be used productively". They explain that in trains this is also often the case.

So, the value of time probably will change. However, as in level 3 the vehicle cannot drive whole trips on its own and drivers might not use the time productively, the reduction of the value of time will not be extreme. As value of time is a quite abstract concept, some references are needed. Gucwa (2014) has four scenarios for value of time: no change, the same as public transport, half of what it is now and zero. Snelder et al. (2015) lower the value of time of commuters with 10% in one of their scenarios. Other references can be the value of time in public transport. However, average values of time per mode are hard to compare as different types of people use these modes. Sometimes the relation between car drivers and passengers are made. Car passengers are given 80% of the value of time of the driver (Snelder et al. 2015). The source of this figure is doubtful as it is derived in an old expert meeting.

FINDINGS ON CHANGES IN VALUE OF TIME
For level 1 and 2 no changes are expected as doing something else while driving is not allowed. For level 3 both development paths are equal. Inner city traffic is expected to be too busy to work, so there is no value of time decrease there. For rural and provincial traffic the value of time of 90% of the current value is expected, bandwidths from 80 until 100% are also researched. For highway traffic 80% is expected, with bandwidths from 70-90%. For both scenarios the same values are assumed.

table 5-3: Only in level 3 automation on rural, provincial and between cities will lead to a change in value of time.

Changes in value of time	Road type	Autonomous and Cooperative	
		Expected [%]	Upper and lower bound
Level 0	all	100	
Level 1 & 2	all	100	
Level 3	Inner city	100	
	Rural	90	80-100
	Provincial	90	80-100
	Between cities	80	70-90

5.4. Capacity effects

Automated vehicles can influence the capacity of the road (Hoogendoorn et al. 2014; Snelder et al. 2015). The influences on capacity can be divided into four factors which together influence the modelled capacity: the capacity of a road stretch, the capacity drop, shockwaves and network effects. As this research investigates mixed traffic, impacts like a higher free-flow speed are not taken into account.

All impacts summarized into one parameter in the model: the capacity of a relation
The capacity in this model is not the capacity of a single road stretch, but the capacity of a relation. This consists of different roads, bottlenecks, intersections and roundabouts together having a capacity. All impacts automated vehicles have on traffic flow need to be summarized in one parameter: the PCU for automated driving. PCU stands for Passenger Car Equivalent and is normally used to model trucks. The volume of a specific user class is multiplied with the PCU to get the actual volume. Where the PCU for trucks is mostly between 1.8 and 2, the PCU value for automated vehicles will probably be lower than 1, for instance 0,9. This means that automated vehicles take less space on the road than normal vehicles.

Changes in capacity of a road stretch
There are many studies done to capacity effects of automated vehicles on a single road stretch (Snelder et al. 2015). All studies are microsimulations which simulate a road (often 2 lanes) without bottlenecks. Data from field tests are scarce, which makes that many simulations are not validated. Still, as field tests are scarce, microsimulations are the only source to rely on. These simulations point out that theoretically the capacity can double due to automation (Shladover et al. 2012). However, studies with more bottlenecks show way lower figures. Outcomes of the simulations are ambiguous, however a few outcomes can be derived:

For cooperative driving capacity benefits only arise after 40% penetration of communicating vehicles
In many studies to cooperative automated cruise control (CACC) impacts only visible arise after a penetration rate of 40% (van Arem et al. 2006; Wilmink et al. 2014; Arnaout & Bowling 2011; Ngoduy et al. 2009).

In a cooperative development path on a road with bottlenecks the capacity rises around 5%
The impact on roads with bottlenecks is low. Wang (2014) finds a capacity rise of 10% in a simulation of a bottleneck on a road of 14 kilometres. Van Arem et al. (2006) find only 5%. Both studies use rather simple bottlenecks (a lane drop and a speed drop), in real world traffic more complicated bottlenecks are present. Therefore, a 5% improvement (at maximum penetration rate) is possible due to connection in automated vehicles.

Impacts of autonomous systems (not cooperative) are slightly positive or slightly negative
Simulations studies of ACC show almost no capacity changes (Shladover et al. 2012; Van Arem et al. 1996). This holds for all autonomous levels.

ACC and CACC only have a positive effect if the headways are smaller than a human driver would do
In research many different following times are used. Positive effects of automation can only be seen if shorter headways are used (Snelder et al. 2015).

Almost all studies to capacity effects for automated vehicles are done on highways. The impact on provincial roads are assumed to be comparable (maybe slightly lower due to more intersections). Capacity studies in urban environments are scarce. In this study it is assumed that automated vehicles do not influence the capacity of a single road in an urban environment positively, as here the capacity is determined by the capacity of traffic lights (which are discussed in the a coming paragraph). However, automated vehicles could also have negative effects on capacity. Current test vehicles are now programmed to be very safe and therefore keep longer distances than normal cars do. A blogger living in Silicon Valley even explained the self-driving Google Lexus drives 'like your grandma' (Hackett 2015). Therefore, also negative effects on capacity will be investigated.

Capacity drop has a small effect on highways, the same effects occur in cities
The capacity drop arises because drivers tend to keep longer distances to their predecessors, the moments after congestion. There are a few studies done to capacity drops and automated vehicles (Van Driel & Van Arem 2010; Kesting et al. 2010; Kesting et al. 2007). Theoretically, and shown in microsimulations, ACC or CACC could overcome the capacity drop, but how much it changes capacity is not clear. What is known is that the effect is positive. Still it is hard to relate the capacity drop to the capacity in the model. As this is hard to make and not expected to be much, this is not taken into account.

The same effects as the capacity drop occurs in inner city traffic when driving away from a traffic light. Automation has a very short reaction time and therefore the saturation flows could go up. This can have a significant effect on traffic flows as traffic lights determine the capacity of urban networks. Therefore, we expect that the relation capacity will increase by 5% (at full penetration rate) due to this effect. Both for autonomous and cooperative driving, for level 1, 2 and 3.

Shockwaves are decreased by ACC and CACC
The phenomenon of cars braking and speeding up again is called a shockwave, or a stop and go wave. These effects mostly happen on highways. These shockwaves lead to more unsafety, but also influence congestion, as they are a trigger for congestion. Therefore, they influence the capacity on a relation. Research on shockwaves points out that both ACC or CACC can reduce shockwaves (van Arem et al. 2006; Calvert et al. 2011; Schakel et al. 2010). Just as with the capacity drop this effect is hard to translate to the PCU for automation. What is expected is that this effect only occurs on highways in both development paths, and will not be large in relation to the capacity of a road.

Cooperative driving can distribute traffic over network
If a traffic manager knows where cars are, travel times can be predicted more accurately and improved traffic management becomes possible. New ways to distribute traffic become possible with more and more reliable information. The case that vehicles are not only informed, but that also explicit route choices are made by a traffic manager are not taken into account.

On the topic of steering automated vehicles over a network, no studies can be found which give quantitative insights. This makes the translation to capacity on a relation (which consist of multiple roads over which traffic can be distributed) hard. What can be concluded is that the effect will be positive and occurs for all levels of cooperative driving.

FINDINGS ON CAPACITY PARAMETERS

From the literature it can be concluded that the capacity benefits from early forms of automated vehicles are in the range of + and – 10%. In urban environments small capacity advantages arise due to higher saturation flows. Bandwidths of also 10% less capacity in cities is taken into account, since automated vehicles can be too careful with cyclists and pedestrians. For other roads small improvements and small deteriorations are taken into account. For level 3 cooperative vehicles extra benefits arise after a 40% penetration rate. These effects arise the strongest on highways, and to a lesser extent on rural and provincial roads.

Modelling capcity for autonomous and cooprerative vehicles

Last section made clear which capacity effects can arise, this section explains how they can be modelled.

Some effects only arise after a penetration rate higher than 40%

In the case of autonomous driving the effects directly arise with the first vehicle. In that case the PCU of this vehicle becomes 0.95 instead of 1. This is shown in the left graph of figure 5-1. For cooperative driving some extra effects arise after 40% penetration rate (middle graph in figure 5-1). This penetration rate is the sum of all communicating vehicles, so the level 1, 2 and 3 vehicles together make the penetration rate. This assumes that the vehicles are equipped such that level 1 and 2 vehicles can be followed by level 3 vehicles. For autonomous driving only the first mechanism plays a role, for cooperative driving both mechanisms play a role. This leads to the right graph. The exact figures for the PCUs are shown in table 5-4.

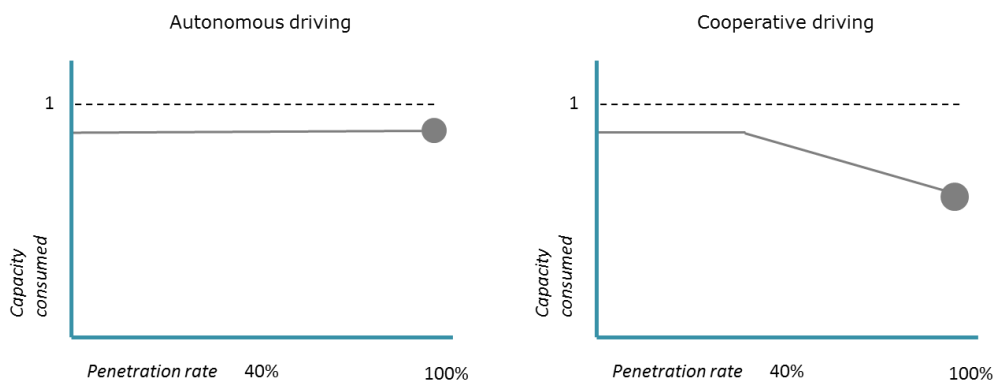*The PCU factors plotted against the penetration rate for the two development paths*

figure 5-1: Two capacity effects are modelled: autonomous driving effects (left) and cooperative driving effects (right). The starting point of the graph is the shown in table 5-4, just as the amount of extra decrease due to cooperative driving.

table 5-4: **table 5-4:** The PCUs (PCU$_L$) for the two development paths. The figures are how much one vehicle 'consumes' of the capacity. As well the expected figures as the upper and low bound are shown.

		Autonomous (A$_L$)		Cooperative (C$_L$)	
		Expected [-]	Upper and lower bound	Expected [-]	Upper and lower bound
Level 0	all	1		1	
Level 1 & 2	Inner city	1	1.1 – 0.9	1	1.1 – 0.9
	Rural	1	1.05 - 0.95	1	1.05 - 0.95
	Provincial	1	1.05 - 0.95	1	1.05 - 0.95
	Between cities	1	1.05 - 0.95	[0-40%] 1	
				[40-100%] Decreases till 0.95	1 – 0.8
Level 3	Inner city	0.95	1.1 – 0.9	0.95	1.1 – 0.9
	Rural	1	1.05 - 0.95	[0-40%] 1	
				[40-100%] Decreases till 0.95	1 – 0.9
	Provincial	1	1.05 - 0.95	[0-40%] 1	
				[40-100%] Decreases till 0.95	1 – 0.9
	Between cities	1	1.05 - 0.95	[0-40%] 1	
				[40-100%] Decreases till 0.9	1 – 0.7

Incorporating these values in the model

All these aforementioned aspects on capacity influence two factors described in section 4.5: the *PCU for level 1&2* and *PCU for level 3 vehicles*. These PCUs are calculated with the following formula:

$$PCU_l = A_l - \left(CC_L * \text{MAX}\left(0 \text{ AND } \frac{\% \ comm. \ veh. - neutral}{1 - neutral}\right)\right) \qquad (7)$$

Where:

PCU$_l$	PCU factor for automation [1/veh]	comm. veh [-]	The percentage of communicating vehicles (Σ level 1, 2 and 3)
A$_l$	Autonomous factor [-]	Neutral [-]	The neutral fraction
C$_l$	Corrected communication factor [-]		

l means the value differs per level of automation (SAE)

In this research the *neutral fraction* is set to 40% and the *autonomous factor* is set as is shown in table 5-4. This formula is the mathematical expression of the graph shown on the right in figure 5-1. The *communication factor* is calculated in a slightly different way, which is explained in the next paragraph.

Simulating a mix of cooperative and autonomous vehicles

The SD-model makes it possible to simulate a mix of cooperative and autonomous vehicles. As shown in table 5-4, the cooperative vehicles have an extra benefit after 40% penetration rate. Below this penetration rate the model assumes no difference in autonomous or cooperative vehicles. The model can simulate a mix of autonomous and cooperative vehicles by calculating the *percentage of communicated vehicles* and the *communication factor* from equation 7. They are determined the following way:

$$comm.\,veh. = (Level\,1\,\&\,2 + Level\,3) * \%\,cooperative \qquad (8)$$

$$CC_L = C_l * \%\,cooperative \qquad (9)$$

Where:

CC	Corrected communication factor [-]	Level 1&2 Or 3	% of level 1 & 2 and 3 vehicles on the relation
% cooperative	% of cooperative vehicles on the relation		

l means the value differs per level of automation (SAE)

In mixed traffic the effect of communication is decreased in two ways: it gets harder to reach the 40% threshold (see equation 8) and the impact of cooperative driving gets less (see equation 9).

5.5. Fuel economy

Two fuel economy effects play a role when the fleet is automated. The first is that automated vehicles accelerate and decelerate smoother than normal drivers and therefore fuel is saved (Snelder et al. 2015). Another effect is that cars can drive closer to each other and that air resistance can drop (Litman 2014). The first effect happens directly with the first introduction of an automated vehicle. The second effect only happens in the cooperative development path and only arises after there is a certain percentage of cooperative vehicles on the road. This is the same method as is used for the capacity effects. A schematic overview of this method can be found in figure 5-1.

Gucwa (2014) assumes that the sum of both effects is 15%. This research assumes that automated vehicles have a 5% gain and connection can lead to a 10% extra gain. This 10% only arises at 100% penetration rate of cooperative vehicles. From 40% on, these platoons can be formed and benefits start to grow. Table 5-5 shows an overview for the exact benefits relation type.

Table 5-5: For autonomous and cooperative directly some benefits arise due to more efficient driving. For cooperative driving the air resistance benefits arises after 40% penetration. This benefit is small in cities and larger on highways.

Fuel economy benefits		Autonomous & cooperative	Extra benefit for cooperative (arise after 40% penetration)
Level 0	all	0	0
Level 1 & 2	all	-5%	0
Level 3	Inner city	-5%	0
	Rural	-5%	-5%
	Provincial	-5%	-5%
	Between cities	-5%	-10%

Simulating a mix of cooperative and autonomous vehicles
Just as with capacity, cooperative vehicles have an extra benefit after 40% penetration rate. In mixed traffic it gets harder to reach the 40% threshold and the impact is lower. A similar approach as with capacity is chosen to take these effects into account. The set up with a *PCU* for capacity is used at the fuel consumption with an *efficiency factor*. This factor is calculated the same way as the PCU (see equation 7).

5.6. Modelling automated trucks

Just as passenger cars, also heavy goods vehicles can be automated. This model only takes the influence of automated trucks on capacity into account. The same method for passenger cars as for trucks are used. Therefore trucks have two PCUs. One to calculate a normal truck to normal car (traditional PCU: 1,8) and a second to make them automated (the new PCU: around 0,9). Fuel economy and value of time are not taken into account, as they would only influence the mode choice and time of day choice which are left out of the model.

It is assumed that heavy goods vehicles only platoon with other heavy goods vehicles, as being followed by a truck can be quite scary for a passenger car. The other way around is not taken into account to make the model not too complicated. Furthermore, it is assumed that automated trucks can find each other more easily in traffic to form platoons, as they now already do so without automation. Therefore, the 40% threshold is set to 20%. As a result, from 20% penetration rate connection effects can arise.

6   Testing the model

Chapter 4 and 5 explain the model structure. These chapters present the results of the third and fourth sub-question: *what is the best way to model the impacts of automated vehicles* and *what are the mobility impacts of early forms of automated driving on the isolated elements of the transportation system?* This chapter explains in which situations and under which circumstances the SD model can be used. This means that in the end the results of the fifth sub-question can are shown: *what are the results of a validation test?*

The goal of the model, an explorative model to study the impacts of level 1,2 and 3 of automated vehicles, should be kept in mind. The model does not have to be able to simulate all details of automated vehicles, but only the most important dynamics.

The model consists of three constructs:
1. Simulating the base year
2. Simulating changes in mobility due to automated vehicles (level 1, 2 and 3)
3. Simulating other exogenous changes affecting mobility

The first and second point are the core of the model, therefore more attention is payed to testing these points.

First static tests of the model are performed, followed by dynamic testing of the model. This dynamic testing of the model is done in two environments as is summarised in figure 6-1. The experimental phase uses the same simulation environments.

Lab environment	'Real world' environment
• The world stays as it was in 2013 • No exogenous changes, only introduction of automated vehicles • Only simulating aspect 1 and 2	• Introduction of automated vehicles, and changes in exogenous factors • Simulating aspect 1, 2 and 3
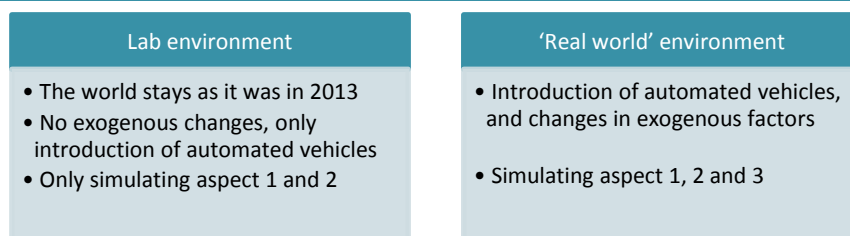
figure 6-1: The two experimental set-ups for the model.

The most relevant tests from the book Business Dynamics of Sterman (2000, p.852) are performed on the model. In table 6-1 an overview is given of the tests of this research. The tests and its results are described in more detail in the next sections.

table 6-1: Overview of all tests performed on the model.

6.1 Static tests	Goal and structure test	Is the structure of the model adequate to meet the goal?
	Boundary Adequacy Test	Are the boundaries of the model set right?
	Units check	Are the units modelled right?
6.2 Robustness and sensitivity	Extreme value test	How does the model perform under extreme values?
	Sensitivity test	Is the model sensitive to changes in the inputs?
	Comparing sensitivities	Do the LMS and the SD-model have similar sensitivities for the mode choice?
	Impact of sensitivities	What happens when the sensitivities are 10% higher or lower?
6.3 Base case	Explanation of the base case	Can the behaviour of the base case of automated vehicles be explained?
6.4 Assumptions	Assumption check	Do the assumptions the model is based on hold under normal circumstances?
6.5 Comparison for exogenous data	Back cast & start point	Can the model back-cast 2000 correctly? Does the modelled data of 2010-2013 similar to OViN data?
	Comparison LMS 2030	Do the LMS and the SD-model show similar results for exogenous changes?
6.6 Comparison with other AV models	LMS (Dutch)	Do the LMS and SD-model show similar results for simulating automated vehicles
	OTM (Danish)	Do the OTM and SD-model show similar results for simulating automated vehicles?
	TMO (USA)	Do Travel Model One and SD-model show similar results for simulating automated vehicles?

6.1. Static tests

For the static tests, there is not model run performed, but the structure of the model is investigated. The model is investigated by several experts and the model's structure is compared to literature.

Goal and structure test

The goal of the model is to simulate the impacts of early forms of automated vehicles on mobility in the Netherlands in an explorative way. To test if this goal is met, the model is compared to other models and literature. Furthermore, several experts[28] are asked to review the model is given.

Simulating mobility in the Netherlands

As is described in the requirements (section 3.1) both supply and demand have to be simulated in order to simulate all effects on mobility. The model captures both. The model is built according to same principles as the ScenarioExplorer (1999a). Some aspects are modelled more elaborate than in

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[28] The expert judgement consist of meetings with the committee members Rob van Nes (TU Delft) and Maaike Snelder (TNO / TU Delft), and one of the developers of the ScenarioExplorer and top advisor at Rijkswaterstaat Erik Verroen. First the model is discussed without showing them the model. Next step is to show the model and investigate with them the structure. Next the model is run.

the ScenarioExplorer (time of day choice), others are modelled more briefly (trip generation, overlap factor). This is done as the purpose of both models differ. In this study the emphasis is on the steps where automated vehicles will have most influence. In contrast to other models the level of aggregation is higher. Where models like the LMS simulate on household level, the SD-model simulates on relation level. As the goal of the model is explorative this abstraction level is considered to be permissible.

Due to this aggregation not all factors which play a role in mobility are simulated. Some play a larger role than others. The most important are discussed here:

- In the current set-up a constant overlap factor is used. This means that all overlapping relations change in the same way over time as the investigated relation. If, for example, demographic growth differs per zone, this is now not taken into account. A dynamic *overlap factor* and simultaneous simulations would be the solution to overcome this.
- The assignment is too simplistic to grasp all traffic flow characteristics. The BPR-function is a good way to project what will happen on average, but an explicit network has the possibility to simulate more effects. Downside is that an explicit network harms the explorative nature. In the future work ways to work around this are presented.

Equation test

To check if no errors are made in the SD-model, a check is performed. The first time step of the model is re-calculated in Excel. A small difference is found as Vensim uses 4 digits per number in its calculation. Also the concept of 'conservation of people' is checked. This means that the input of people should be the same as the output. The sum of the mode choices are summed up and indeed have the same number as the amount of trips generated for all tested years.

Simulating automated vehicles

Three effects of automated vehicles are modelled:

- Capacity changes (via PCU)
- Fuel economy changes
- Value of time changes.

In other literature these three effects are most often modelled (Snelder et al. 2015; Gucwa 2014; Tetraplan 2015). However, these models simulate the effects for all vehicles, instead of for a share of the vehicles. This model is unique since it simulates on a large scale effects of mixed[29] forms of automation. The concept of an PCU factor per level which varies over the penetration rate is novel.

Nevertheless, not all effects of automated vehicles are simulated. The capacity effects are simulated more elaborately than in other macroscopic studies. Nevertheless, an explicit network opens even more doors to simulate the same effects more accurate and also other effects. Due to the use of a speed-flow diagram relations from literature are hard to translate into parameters for the model.

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[29] With mixed forms of automations two types of mixes are meant: mixed in levels, so no automation, level 1 & 2 and level 3 automation, but also the possibility to communicate. The SD-model can also simulate different shares of communicating and autonomous vehicles.

The main point of criticism in the expert judgement is that longer trips due to automated vehicles are not modelled. Other less important aspects which are not modelled are changes in parking environment, a mode choice for trucks and spatial changes due to the automation of the fleet.

The time horizon, modelling until 2050 seems valid, as than level 4 and 5 are expect to have a share of 5% and from then on significant impacts.

Simulating exogenous changes
Besides automated vehicles also other aspects influence mobility, for example demographic growth. These aspects are not the core of the study and are less elaborately taken into account. Only the points mentioned in the starting point document, the demographic growth and the increase of the road network are modelled. These aspects are the most important, however, not an exhaustive list. The most important aspect which is missing is a division of the population in age or income classes and a way to take extra roads build more accurate into account. With this division on population segments and ageing population could be taken into account, with different travel patterns. With a network, changes in the road infrastructure could be taken more accurately into account.

FINDINGS ON THE GOAL AND STRUCTURE
The structure of the model seems adequate to simulate the effects of automated vehicles in the Netherlands[30] on an explorative level. Main points of criticism are that not all effects of automated vehicles are captured, the model simplifies aspects in modelling transportation and not all exogenous changes can be taken into account due to the set-up of the model. However, the goal of the model is to capture the most important aspects, which it does.

Boundary Adequacy Test
The boundaries of the model are checked. For all values should hold that they are not influenced by automated vehicles. All exogenous variables are presented in appendix C. For most variables holds that they are not influenced by automated vehicles, a few are discussed here:

- *Travelled distances by car*. In the model a change in destination choice is not taken into account. The travelled distance can change if the value of time of cars or the average speed on a relation changes. The LMS (Snelder et al. 2015) and Gucwa (2014) take this into account. In the assumptions part of the test chapter is elaborated upon this aspect.
- *Number of trips.* The trips made per person could change if the value of time changes. This effect is expected to be small until level 3, but for level 4 and 5 this could arise.
- *% of car owners.* If automated vehicles are a huge success, it could be that more people buy an automated vehicle. The same could be true for the amount of level 1 & 2 and 3 vehicles on the road. This however, is taken into account by Niewenhuijsen (2015) in his model.
- *Number of HGV trips.* In the SD-model no mode choice is made for trucks. If the costs of transporting or the travel time decrease due to automation, the mode choice could change. For more elaborate models this should be taken into account.

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[30] Due to time limitations not all relations are simulated, however, the model is able to simulate all 42 relations, therefore the whole of the Netherlands could be simulated with the SD-model.

Besides these 'missing' or neglected feedback loops the most important ones are taken into account: from travel time back to the utility functions for the mode choice and the time of day choice.

Units check

For the model a units check is performed. All variables are given units. Vensim has the ability to check the units. No inconsistencies are found. Important to note is that the value of time and travel time are in minutes, as OViN reports the travel time in minutes. For the speeds this is converted to kilometres / hour.

6.2. Robustness and sensitivity

This section presents the first dynamic tests of the model. The behaviour of the model under extreme inputs and the sensitivities of the model are tested.

Extreme value test

The goal of this test is to check if the model holds for basic physical laws and checks if all equations also hold under extreme conditions. For all tests the *lab environment* is used. This means that the world stays like it is in 2013, except for one aspect: the introduction of automated vehicles. The complete results are shown in appendix D.

The model shows logical behaviour for almost all parameters. There are a few striking points which are highlighted. These points give no problems for the normal functioning of the model, but show in which extreme cases the model is not applicable anymore.

Striking points from the analysis
Passengers can travel when there are no cars – or with too many passengers per car
Car drivers and car passengers are separate modes in the model, without a connection. The only link is that their travel times and distances are the same. So if cars get unattractive and passengers attractive, the model simulates too many passengers per car (more than 4) or even passengers without any cars. The case that this would happen is rare, as the main reason for cars to get unattractive is due to high travel times, which also make being a passenger unattractive. Very high fuel costs or an extreme change in value of time for one of both can lead to impossible situations. In the LMS, and many other macroscopic models, the modes are also not linked, so this problem might also arise.

With extreme population growths the model starts oscillating
When the population grows with more than 15% per year, the speeds and the amount of people traveling during peak hours start oscillating. Due to the rise in population, roads start to congest and speeds drop. As a result no car trips are made and the average speed on the road rises immediately. This flip-flopping effect does not occur in normal behaviour as the growth is normally around 0.3 until 0,8% per year. If a smaller time step is chosen this effect arises with higher percentages of growth. With a time step of 0.0078125 (3 days) this effect arises at doubling in population (100% growth) per year. A smaller time step is not used in the model as the cases in which it is needed are very rare, and it has an effect on the calculation time.

With extreme inputs the model needs 5 years to stabilise

When the input parameters in the year 2000 (the start of simulation, warm-up until 2013)[31] are extreme the model takes 5 years to stabilise. As the modal split in 2000 is calculated with exogenous road speed (road speed from OViN, on which the capacity is also calibrated), a change in capacity, free-flow speed or utility changes the output after one time step considerably. Within 5 years this unbalance is stable again. It is unlikely that effect occurs within normal simulations, since all exogenous changes are spread out over time and not at the start of the modelling. Still, if one would like to simulate the effects of an instant population doubling, the model would show extreme results. For less extreme cases the model stabilises more quickly. The time step has no influence on the amount of years to stabilise. This has to do with the delay of the feedback.

When the peak gets very unattractive car usage rises

When the peak is very unattractive (not due to low speeds, but due to a high constant, for instance by road pricing), less cars drive during peak hours. Due to this rise in speeds during peak hours, and as cars move to the shoulders of the peak, speeds will probably drop outside of the peak. However, the utility of the car is calculated based upon speeds during peak hours, which result in more attractive cars. Thus, the model only holds if the speeds during peak hours are lower than (or around) the speeds outside the peak. In the Netherlands almost all models are peak hour models, which use this assumption.

Sensitivity test

In this sensitivity analysis is tested if the model behaves logical for small changes in the inputs (Sterman 2000, p.861). Input changes of +10% and -10% are compared with the normal behaviour. This analysis is performed on 12 parameters:

1. Demographic growth & growth of trips HGV
2. Free-flow speed
3. Capacity of the road
4. PCC level 1, 2 and 3
5. Utility of the train
6. Utility of BTM
7. Utility of slow
8. Utility of passenger
9. Utility of level 0
10. Utility of level 1 & 2
11. Utility of level 3
12. The time of day constant

Some of these are groups of variables, such as the utility, which is calculated from several parameters. In this case a multiplier is added, which normally is 1, but varies from 0.9 until 1.1.

For almost all simulations the results are logical. If the inputs are varied 10%, the outputs roughly do the same. A few points are discussed in this section. They all can be explained and do not lead to less appropriate use of the model. The total results are shown in appendix E.

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[31] The base year of the model is 2013. However, as in the tests the input parameters vary and different scenarios are tested a warm-up period is introduced. From 2000 on the model can stabilise. This is done to prevent small errors if input differs.

Striking points from the analysis
The first 5 years the model needs to stabilize
Just as is shown in the extreme value analysis, the model needs to stabilize the first five years. As the modal split in 2000 is calculated with an exogenous road speed (road speed from OViN, on which the capacity is also calibrated), a change in capacity, free-flows peed or utility of a mode bring the start in unbalance. Also with an input change of +/-10% , some years are needed to stabilize. This is not harmful for the model as analysis are performed from the year 2013, and the model starts running in 2000. However, in the experimentation the first years might show to some oscillation.

Time of day choice is less sensitive than the mode choice
When the road speed or utilities change + or – 10%, the mode choice reacts accordingly. The time of day choice however, only changes 5%. It seems that the mode choice is most sensitive. One could argue that changing the preference for traveling in- or off-peak is not that hard as changing modes. However, also the opposite can be defended: a change in departure time (peak is 2 hours, so you would have to change your departure time on average 30 min), can be hard as offices or schools often have rigid starting times.

Symmetric changes in utilities show asymmetric outputs in speeds and mode choice
When for instance utilities are changed + and – 10% the speeds and mode choice show a asymmetric pattern. This seems strange, but can be explained, both with different reasons. The form of the speed-flow curve makes that less car traffic leads to a slightly higher speeds, but more car traffic leads to a lot lower speeds. For the preference in mode choice a same pattern can be seen, however this has another reason. Here the exponential term in the utility function leads to asymmetrical behaviour.

Sensitivities compared to LMS
The sensitivities of the model can be compared with other models. There are many elasticities of the LMS available (Willigers & de Bok 2011), however, only a few are comparable to the SD-model. As the LMS only reports on elasticities per trip purpose and the SD-model only gives outputs per relation, which makes a comparison hard to make. However, there is one variable which can be compared: the sensitivity for a change in mode choice as the travel time differs.

Results

The elasticities of the LMS and the SD-model are compared in figure 6-2. The elasticities of the LMS are derived from a significance report on elasticities (Willigers & de Bok 2011, p.116).

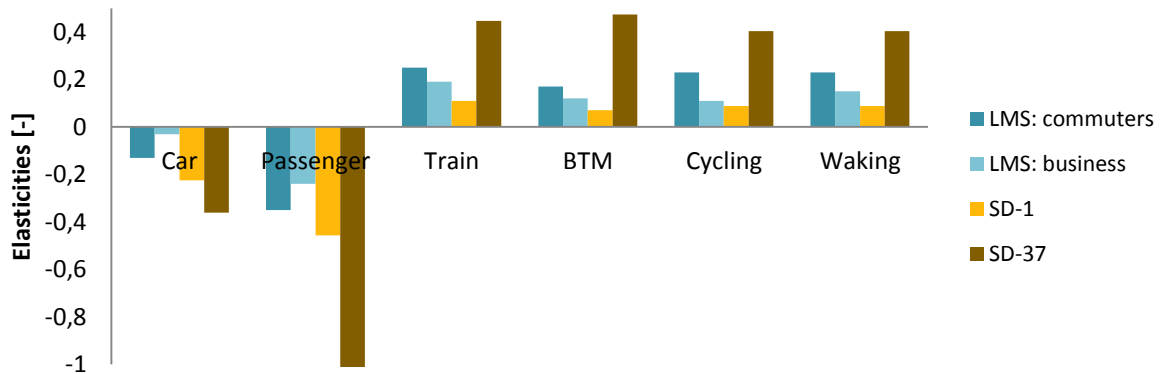*Comparison sensitivities LMS and SD-model for travel times*

figure 6-2: The sensitivities for a longer car travel times on the mode choice of the LMS (Willigers & de Bok 2011, p.116) compared to the SD-model. If the car travel times rise with 1% the mode choice changes with the projected percentage.

What can be seen is that the elasticities for both models have the same directions and are in the same range. It is also logical that for the SD-model holds that relation 37 is more sensitive than 1, as relation 37 is a typical car relation. What can be seen is that the average of both relations is relatively more sensitive than the LMS. However, other more car oriented relations (such as relation 36, accounts for 40% of the trips) will have sensitivities like relation 37. Therefore, it was found that the SD-model is more sensitive in the mode choice than the LMS. Textbox 2 explains why the SD-model is more sensitive.

For the time of day choice and the assignment no good comparison can be made with the available LMS elasticities.

Sensitivity of the scale parameter

From the other analysis in this chapter can be concluded that the mode choice of the SD-model probably is too sensitive, or at least more sensitive than the LMS. Therefore will be checked what this means for the simulations.

Set-up of the experiment

The total set of constants and scale factors is a complicated construct. If the scale parameter (μ) of one mode is changed the total mode choice for the start year will differ. This can be compensated by adapting the constant (C) in the formula. First the total mode choice is tried to recalibrate, however, this was more time consuming than expected. Therefore only the effect of one scale parameter is researched.

Two simulations are performed with a different scale parameter for the car ($μ_{car}$): +10% and -10%. These are compared to the base case. Furthermore, to make the runs comparable the constants are also changed. These constants are calibrated in the model. For the +10% case, the constant is multiplied with 0.7012 and for the -10% case the constant is multiplied with 1.365. In both cases the utility of all modes stays the same, only the sensitivity differs. With these values the mode choice in the base year is thus equal to the base case.

Results

The amount of car trips for the three cases is shown in figure 6-3. For the amount of car trips, the differences are quite small. For the speed on the road and the amount of travel time loss hours the differences are in the same range. On the loss hours the sensitivity has the most impact, here 10% higher sensitivity parameters leads to a 1.88% difference, see figure 6-4.
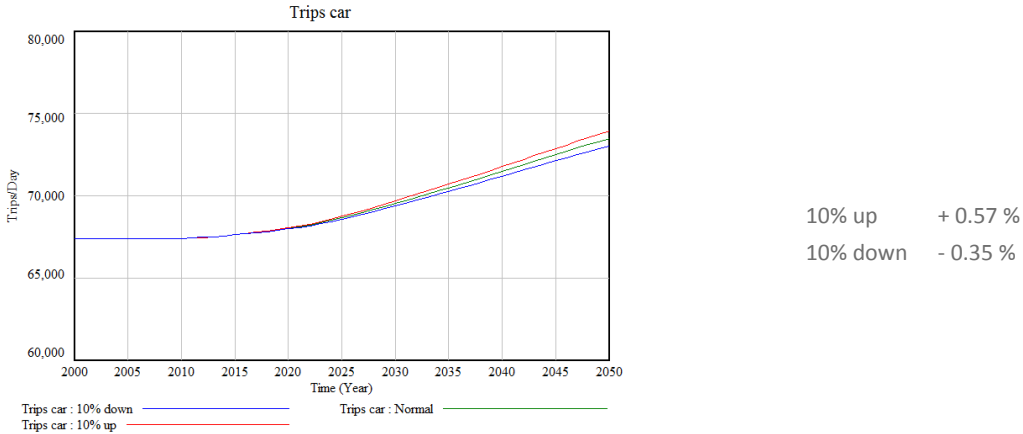

| 10% up | + 0.57 % |
| 10% down | - 0.35 % |

figure 6-3: The amount of car trips for the three cases: base, 10% up and 10% down. This leads to 0.57% extra traffic or 0,35% less.

The analysis shows that the sensitivity of one scale-parameter has no large effect on the amount of car trips made over time, and related effects as average speed or lost hours in traffic. However, this analysis is performed for one scale parameter with a difference of 10%. A more elaborate investigation will show more insights.
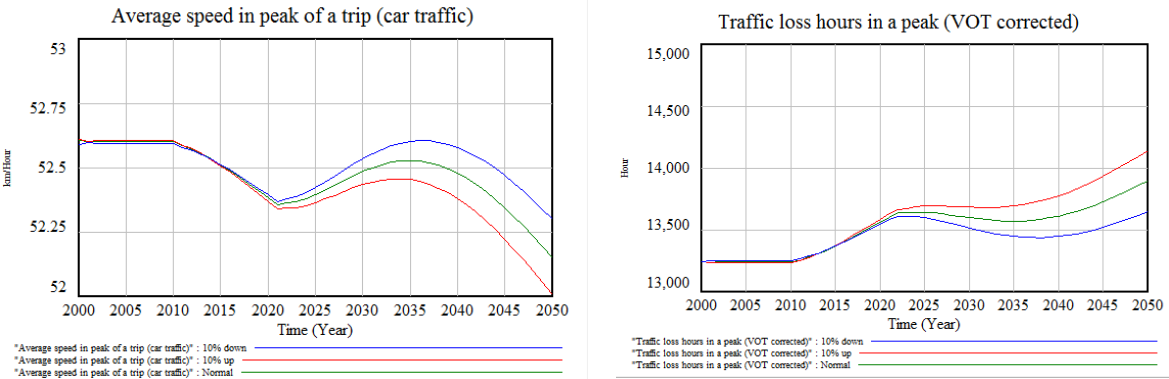

figure 6-4: The average speed and loss hours shown for the three simulations.
The precentral differences for the two simulations are: Speed (up): -0.27 (down): +0.29. Loss hours (Up/down): +/-1.88.

6.3. The behaviour of the base case explained

In the SD-model automated vehicles differ in three ways from normal vehicles: their value of time is less for level 3 and equal for 1&2, their PCU is lower (capacity) and they consume less fuel. In this section the behaviour of the two development paths (autonomous and cooperative) will be explained by the three individual impacts. After the base runs it is investigated how strong the effect of feedback in the model is. All simulations are performed for relation 37 (trips between the four large cities in the Randstad).

The results for cooperative driving are shown in figure 6-5. The results for autonomous driving are shown in figure 6-6. A run with and without feedback is shown in figure 6-7. All these figures show simulations in a lab-environment. The inputs used for the simulations are shown in table 6-2.

table 6-2: The input values for the base case scenario for relation 37. (summary of table 5-1)

	Autonomous	Cooperative	
Value of time			
Level 0	100%		
Level 1 & 2	100%		
Level 3	80%		
PCU (capacity)			
Level 0	1	1	
Level 1 & 2	1	[0-40%]	1
		[40-100%]	Decrease till 0.95
Level 3	1	[0-40%]	1
		[40-100%]	Decrease till 0.9
Fuel economy			
Level 0	1	1	
Level 1 & 2	0.95	[0-40%]	0.95
		[40-100%]	Decrease till 0.85
Level 3	0.95	[0-40%]	0.95
		[40-100%]	Decrease till 0.85

In the simulations 187464 trips are made on the relation, which has a capacity of 118240 vehicles per hour and an overlap factor of 9.27.
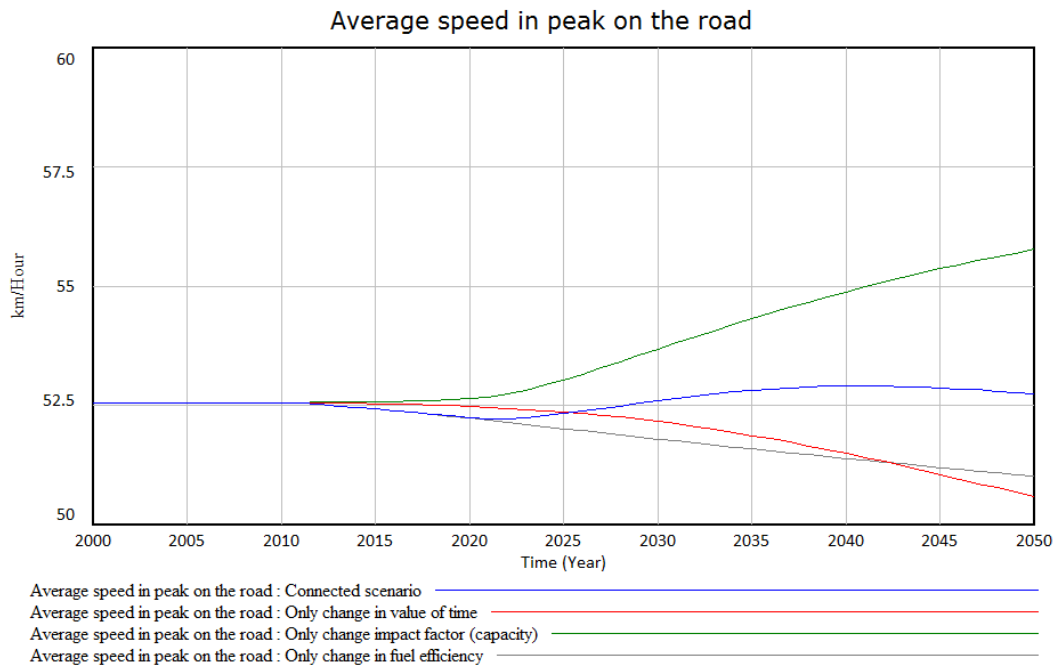
figure 6-5: At first speeds drop due to fuel economy advantages. Followed by capacity advantages which arise after 40% penetration rate (2021). When level 3 vehicles start to dominate (2045) the speeds drop again due more cars on the road as a result of the personal benefits they entail.

With the behaviour of the different impacts the behaviour of the *cooperative path* can be explained. Before 2010, there are no AV's in the model, so there is no change in speed. From 2010 it can be seen that the speed drops, due to the fact that to fuel advantages stimulate people to choose a car as favourite mode of transportation. These fuel economy advantages lead to more vehicles and lower speeds over the whole time horizon of the model. The same is true for the value of time. A lower value of time makes the car more attractive and decreases the speed on the road. This effect starts around 2020 when the first level 3 vehicles are introduced. The lower PCU leads to a higher speed. When the sum of level 1, 2 and 3 cars becomes higher than 40% (in 2021) the cooperative benefits arise and capacity effects grow. When around 2045 the amount of level 1 & 2 vehicles starts decreasing the value of time gains rise and become stronger than the capacity improvements. This will lead to a decrease in speeds.
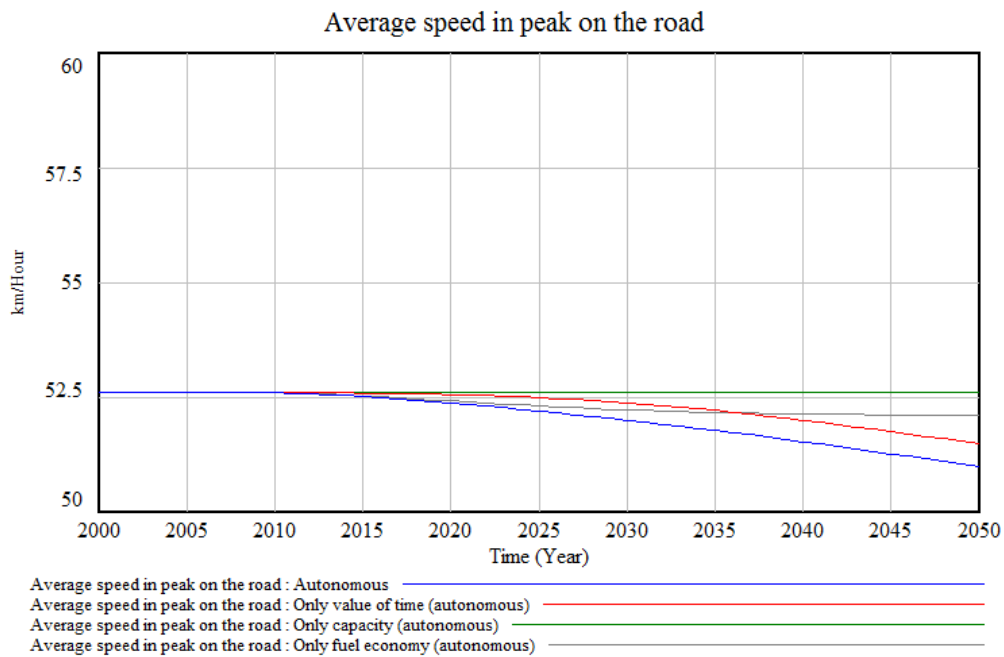
figure 6-6: In autonomous development path the amount of cars rises due to personal benefits. These benefits are a little lower than in cooperative path as fuel savings are lower. Automated vehicles have minimal capacity benefits, therefore the speeds are lower than in the cooperative simulations.

In the autonomous development path it is not possible to platoon with several vehicles. Therefore, capacity benefits do not arise. Fuel economy improvements are smaller than in the cooperative path. Due to this the speeds drop not as much as in the cooperative path (from '10-'25). However, as there are no capacity improvements the average speed during peak hours between the four cities in the Randstad will not rise anymore. Where after 40% penetration rate the speeds go up in the cooperative path this is not the case in the autonomous path.

The model without feedback
By turning the feedback loop from travel times back to the utility functions off, it can be seen if a feedback loop is needed in the model. In the simulation without feedback the perceived travel time on the road (from OViN) stays the same over the years. However, the actual speed on the road still changes.
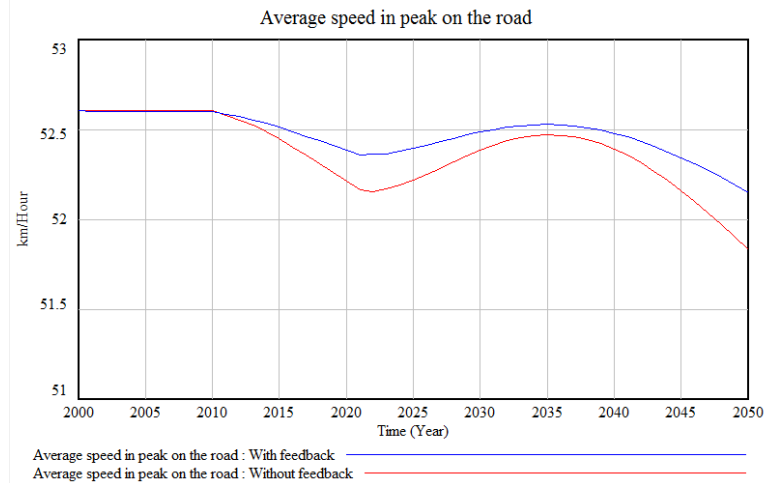
Average speed in peak on the road

figure 6-7: Run with and without feedback for cooperative driving on relation 37. The run without feedback leads to more extreme outcomes as there are no compensating second order effects.

What can be seen is that in the run without feedback reacts more extreme to changes. In the run with feedback there is a compensating effect: due to lower travel times, more people change modes or travel during peak hours. Without feedback there is no compensation. The only reason why people in this development path change modes, is due to another value of time or lower fuel costs.

Not taking the feedback loop into account can be explained with an analogy of not telling anyone that a road is extended with an extra lane. The people on the road will get a higher average speed and no extra traffic will be attracted by the road. With a feedback loop the road will attract extra traffic. The opposite effect happens in this simulation: no one perceives a higher travel time, although there is more congestion.
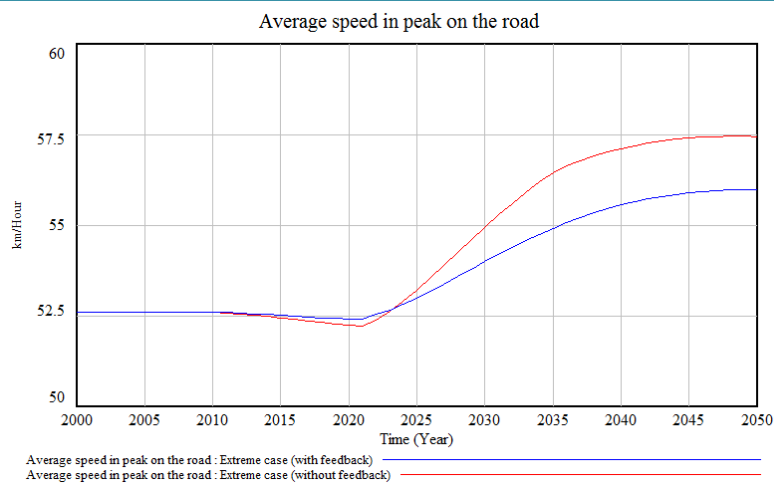

Average speed in peak on the road

figure 6-8: Run with and without feedback on relation 37 for an extreme case of cooperative driving (VoT = 70%, PCU = 0.85). The case without feedback is not compensated by second order effects and therefore reacts more extreme.

From the simulation in figure 6-7 can be seen that the feedback loop has no large influence on the results. The speeds differ 0.32 km/h (0.6%) at maximum. In more extreme cases the differences are larger, such as in figure 6-8, where the most extreme cooperative case is modelled with and without feedback. Here it is 1.47 km/h (2.8%) at maximum. This is unneglectable, but still small. Modelling

without feedback can be used for explorative research, but not all dynamics can be understood. In System Dynamics feedback is not hard to model, but it can be an advantage if multiple models are used. However, downside is that it is hard to defend to a client that you do not model the feedback. Modelling feedback is therefore advised.

FINDINGS SIMULATIONS OF INDIVIDUAL EFFECTS
The behaviour of the cooperative and autonomous path are logical and can be explained by the behaviour of the individual effects. Just as in literature expects (Timmer & Kool 2014; Wilmink et al. 2014; Shladover 2015) the cooperative scenario will lead to higher speeds. However, a compensating effect of fuel economy becomes clear in this simulation. The only striking outcome of the simulations is that impact of the fuel economy might be overestimated in this study. Besides that, it can be seen that the feedback loop has an effect on the outcomes.

6.4. Assumptions check

In chapter 4 and 5 several assumption on the modelling are made. These assumptions are checked in this section. The assumptions are:

1. The introduction of automated vehicles is not influenced by mobility effects of automated vehicles.
2. Spatial effects of automated vehicles can be neglected
3. The overlap factor can be set as a constant

Assumption 1: Introduction of automated vehicles
If automated vehicles are a success and lead to shorter travel times for cars, more people will buy an automated vehicle. In the research of Nieuwenhuijzen (2015) many factors, like price or technology maturity are taken into account. However, a feedback loop from travel time to the introduction is not taken into account. Both the cooperative run as the autonomous run show only mildly changing travel times. With the most extreme inputs the travel time differs 8% (see chapter 7.1). This probably will not lead to many people buying a new vehicle. Therefore this assumption holds.

Assumption 2: Spatial effects
In the model spatial effects are not taken into account. However, literature suggests that automated vehicles can lead to spatial changes (Milakis et al. 2015; Snelder et al. 2015). The most important change in spatial planning is that people may change their working or home locations due to shorter travel times or a different value of time. The travel time does not differ that much (as can be seen in chapter 7.1) the value of time still differs, however, this is only 20%. This still could lead to a change, however, a small one. It is preferred to take spatial effects into account. However, the effort of building the spatial relations in the model is not in proportion to the extra accuracy.

Assumption 3: Overlap factor
In this research a constant overlap factor is used. This means that the change in trips of the investigated relation is equal to the growth of relations with which it interacts in a network. This assumption would be correct if the growths are equal for all zones due to external factors (demography, change in car ownership) and due to automated vehicles. In figure 6-11 (page 75) the growths of the different zones, due to external factors (here the GE scenario of the LMS is used) can

be compared. It seems that the growths differ per zone, but are roughly the same (at maximum 10% point difference per zone). The highways and inner cities differ the most. A difference of 10% between two zones does not mean that there will be 10% extra traffic on a relation. As only a part of the traffic uses the same relation, for instance 30%. This makes that a 10% difference would lead to 3% extra traffic. This 3% might look small, but is not negligible. For new models is advised to make use of a dynamic overlap factor, especially if spatial difference between regions are taken into account.

6.5. Comparing the SD-model for exogenously changing data

To evaluate how accurately the model takes changes of exogenous factors into account, we did two tests. These tests check concept 1 (simulation of the base year) and 3 (exogenous changes) of the SD-model. In the first test the results of the model are compared with historic data with a back-cast. This is done with OViN data of 2000, 2010, 2011, 2012 and 2013. Secondly, it is compared with the LMS, the model that is used by the Dutch government to make forecasts. Both models are compared for the year 2030.

Back-cast for 2000 and comparison with 2010, 2011, 2012 and 2013

The model is calibrated with the summed years 2010-2013 of the OViN movement survey (CBS 2014). In this validation the model is compared to the individual years and a back-cast is made for 2000.

Set-up of the back-cast

For the back-cast 2010 is set as base year. The model runs back in time to 2000. The model is, so to say, run backwards. Between 2010 and 2000 exogenous parameters changed. These are summed up here below.

table 6-3: The exogenous parameters with the change from 2010 until 2000.

Back-casting 2000	Change per year	Source
Population decrease	-0.8 % per year	(Groenemeijer 2014)
Less car ownership	-0.66 %-point	(Beuningen et al. 2011)
Lower PT costs /km	- 1% per year	(CBS 2009), (CBS 2015a)
Car costs/km	Stays the same	(CBS 2009), (CBS 2015a)
Amount of trucks	Stays the same	(CBS 2015c)
Travel time train	Stays the same	(Cbs 2011)
Less road capacity	-0.98%	(Wegenwiki 2015)

The simulations are done for one relation: from and to the four large cities in the Randstad, because this relation easily can be imagined.

Results of the back-cast

The results of the back-cast and comparison to the '10-'13 data are shown in figure 6-9 and figure 6-10. What becomes clear is that the OViN data differs a lot per year and the calibrated data fits in it for all 5 modes (more on the quality of OViN data is in section 4.3). As the years of '10-'13 from OViN

differ much and the data for 2000 is collected with a roughly the same method, the data possibly has its downsides too. However, as far as it can be seen from this single data point, the modelled data of 2000 seems to be in line with the survey data. Especially the three modes with the largest shares (car, train, passenger), fit nicely.

That the back-cast for the BTM and slow modes is different from the survey data can be explained by the quality of the survey, but also by the quality of the model. The quality of the survey seems to lack. The amount of BTM trips on relation 37 in 2012 for instance doubles in comparison to 2011. Especially for the smaller modes the variation is high. On the other hand does the model not take aspects such as new bus routes or cycling lanes into account. These inputs are is too detailed for the model.
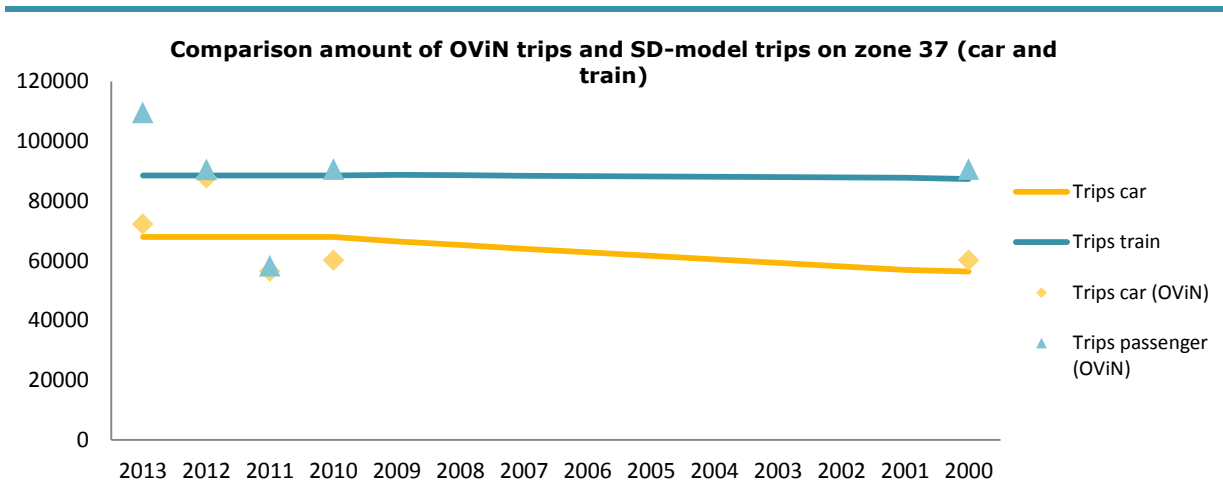

figure 6-9: The line represents the modelled back-cast with the SD-model. The dots are OViN and MON data from a travel survey. This graph only shows the car and train movements for zone 37 (from and to large cities in the Randstad).
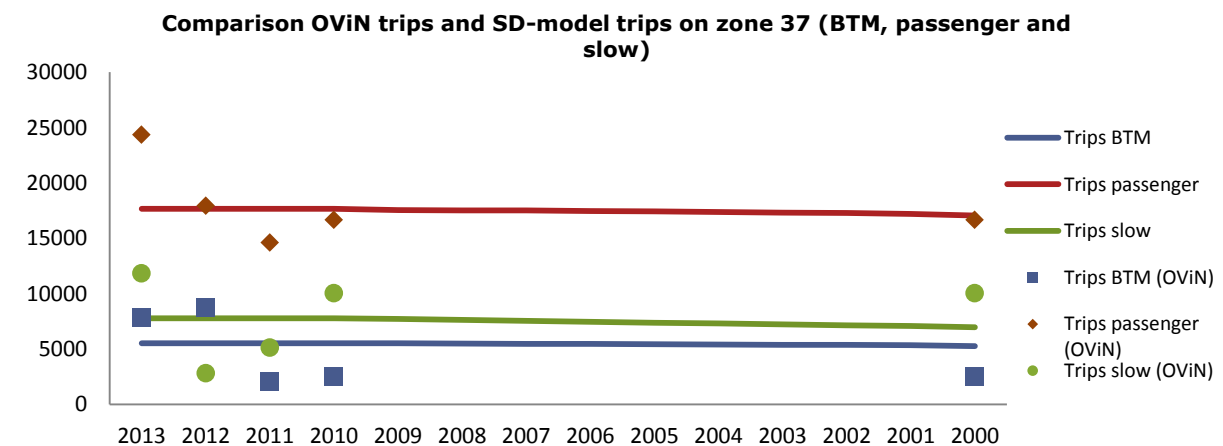

figure 6-10: The line represents the modelled back-cast with the SD-model. The dots are OViN and MON data from a travel survey. This graph only shows the car and train movements for zone 37 (from and to large cities in the Randstad).

Comparison with the LMS without automated vehicles

To compare if the exogenous factors have plausible effects, the SD-model is compared with a run of the model the Dutch government uses for planning: *het Landelijk Model Systeem* or the LMS.

Set-up of comparison LMS

In this run automated vehicles are left out of the SD-model. By doing this the impact of exogenously modelled variables can be compared to LMS. To compare runs the inputs of Rijkswaterstaat's Global Economy scenario created in 2006[32] are used. This scenario assumes extreme growth. For 2040 19,7 million inhabitants are expected in the Netherlands (an increase of 0.6% where this was 0.3% last years).

To make a good comparison the same parameters are used in the SD-model as in the LMS. The '*uitganspuntendocument'* (Ministerie van Infrastructuur en Milieu 2015) and the PBL scenarios from 2006 are used (Janssen et al. 2006). Downside of these documents is that they do not describe all changes between '10-'30 the LMS takes into account. New roads are for instance not mentioned in the document. Still, the most important ones are captured.

Comparing the LMS with the SD-model is hard as the LMS covers the whole of the Netherlands and for the SD-model only 4 of the 42 relations are simulated. In order to make a good comparison the same pattern as the LMS base year is tried to construct. This is done by multiplying the 4 relations with different factors, so the mode choice of both base years would match. This is done with a least square solver. However, the best fit of these 4 relations still leads to 16% mismatched trips. This difference is too large for a good comparison.

Therefore a second method is chosen to come to a good comparison. Here not the base years, but the growths are equalised. The amount of trips per zone are multiplied such that the growth of each relation has the same growth as the LMS. To give an example, if the LMS grows 1 million trips and zone 36 10.000, the trips for zone 36 are multiplied by 100. By normalising the growths the sensitivities of the different models can be compared on magnitude.

Results of comparison LMS

The results of the runs of Rijkswaterstaat for the whole of the Netherlands and the Randstad are compared to the trips of the 4 zones in the SD-model. The results are shown in figure 6-11 and figure 6-12.
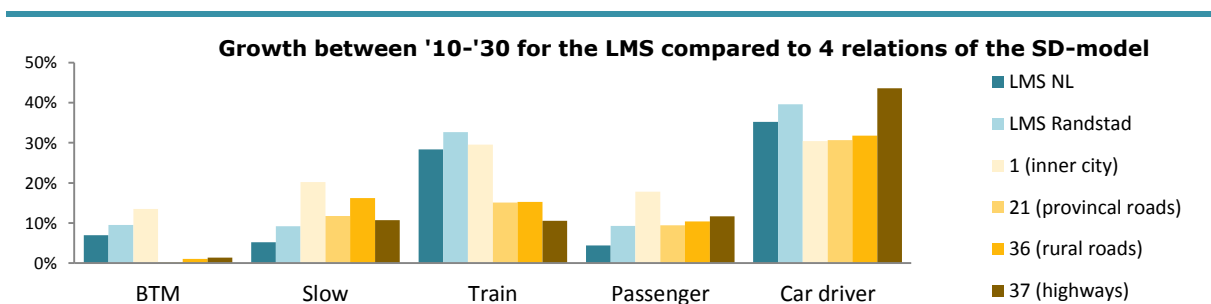

figure 6-11: The growths between '10-'30 per zone in percentages for the LMS (Dutch national model) and the SD-model (4 zones).

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[32] This is a different scenario than is used in the planned LMS study in 2016, although this scenario is also called *Global Economy (GE).* This updated, more mildly, scenario is used as starting point for the experimental runs of the model. However, as the LMS is only run with the old scenario, the SD-model is initiated with different growth figures.

Normalised growth between '10-'30 for LMS compared with the zones of the SD-model
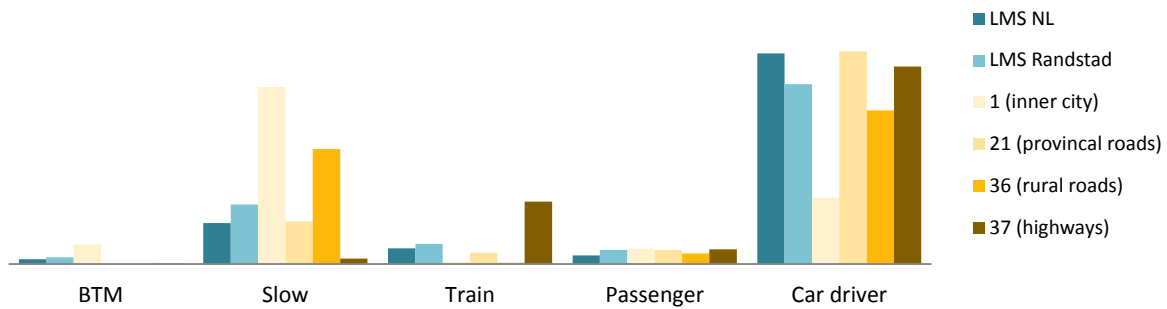
figure 6-12: The growths between '10-'30 per zone are normalised to the same level. This graph shows how the growths are divided over the different modes. <u>Note that the sum of lengths of the bars for each zone are the same.</u>

First, the zones of the SD-model will be compared with each other. The pattern for BTM is logical, more population leads in large cities (where BTM is already popular) to a larger growth than in other zones (both normalised as relative). For slow traffic the same pattern can be seen. BTM does not grow as much as slow traffic. This is because public transport prices rise between '10 and '30 according to the starting points of the LMS. For trains the growth figures in percentages seem strange, but the normalised figures show a logical pattern. In zones where trains are a common mode the absolute growth is high. Where the growth is low the absolute growths are also low. For car drivers both the absolute as the relative growths are logical.

If the SD-model is compared with the LMS it can be seen that the car driver and the passengers show great overlap. The growth in BTM trips is in the LMS somewhat higher, but the in the SD-model only one strong BTM relation is simulated (relation 1). The SD-model shows a higher growth in slow trips than the LMS, the opposite is true for train trips. An explanation for this is that train traffic gets more expensive in the LMS, but probably also a higher level of service. In the SD-model the same is taken into account: higher prices for public transport and a shorter travel time, however, the LMS might also takes new train lines into account. These are not simulated in the SD-model, because they are not mentioned in the documentation.

Findings on comparison for exogenous data

With the two checks, the back-cast and the comparison with the LMS, a combination of aspects is checked: the trip generation, mode choice and feedback with the assignment to the mode choice. Elements such as the time of day choice or the total loss hours are hard to compare with the available LMS data. The time of day choice is not reported on by the LMS. The amount loss hours are calculated in a way different way[33]. Therefore, no good comparison can be made on these aspects.

What can be seen is that both the back-cast as the comparison with the LMS shown logical results. Differences in the back-cast can be explained by taking less variables into account in the SD-model and by inaccurate CBS data to compare with. For the comparison with the LMS also two reasons are

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[33] In the SD-model the loss hours are calculated based upon the difference in *free-flow speed* and *actual speed* times the *amount of trips by car in the peak*. The LMS has a loss hour function in their assignment tool Q-BLOK, which makes a forecast based upon the projected congestion. On average the LMS predicts a doubling of the loss hours, the SD-model projects a 60% rise on average. As the two methods differ a lot no conclusions can be drawn upon them.

given for the differences: a difference in the simulated scope (less relation types) and less exogenous variables taken into account.

As the model scores sufficient for both the analyses, the model can be used for making analyses for the future on the level it is meant for: an explorative level. Certainly not all subtle changes are simulated, but the main trends are in the model.

6.6. Comparing the SD-model with other automated vehicle models

Three other macroscopic studies for automated vehicles can be found: Snelder et al. explored how the Dutch LMS would react on automated vehicles, in Denmark Tetraplan did a similar study for the Copenhagen region and in California Micheal Gucwa is half way his PHD-thesis on simulations for the San Francisco Bay area.

All three researchers highlight the explorative nature of the study. Micheal Gucwa and Chirstan Würtz highlight this in e-mails and Snelder in her report. Still, it is insightful to compare the SD-model to these models.

table 6-4: The SD-model (model created for this thesis, see bottom of the table) is compared with the three models shown in this table. The first two models have a change in only capacity, the third in value of time and capacity. A good comparison for only value of time could not be found in the studies.

Model	Type of model	Area	Changes in AVs	Reported outcomes
LMS (Snelder et al)	Macroscopic	The Netherlands (main roads)	+10% / +15% capacity	Modal split
OTM (Tetraplan)	Macroscopic	Copenhagen region	+ 30% capacity	Modal split
Travel model one (Gucwa)	Activity Based / Macroscopic	San Francisco Bay area	- 50% VoT + 10% capacity - 15% fuel costs	Amount of VKT for cars
SD-model	*System Dynamics*	*4 relations in the Netherlands*		

To make a good comparison the models should have the same scopes. There are a aspects which should be equal: the inputs, the modelled environment and the outputs. Not all inputs of the models can directly be taken over. For instance value of time differences per user class are not able to model in the SD-model.

The modelled environment cannot be changed, however a similar model can be used. Kopenhagen is not in the SD-model, but can best be compared with large cities in the Netherlands, a same approach can be used for San Francisco.

Furthermore, not all steps of the model can be validated. The modal split can be compared with other studies. The time of day choice and change in speeds on the road cannot be related as the other studies do not report on that aspect.

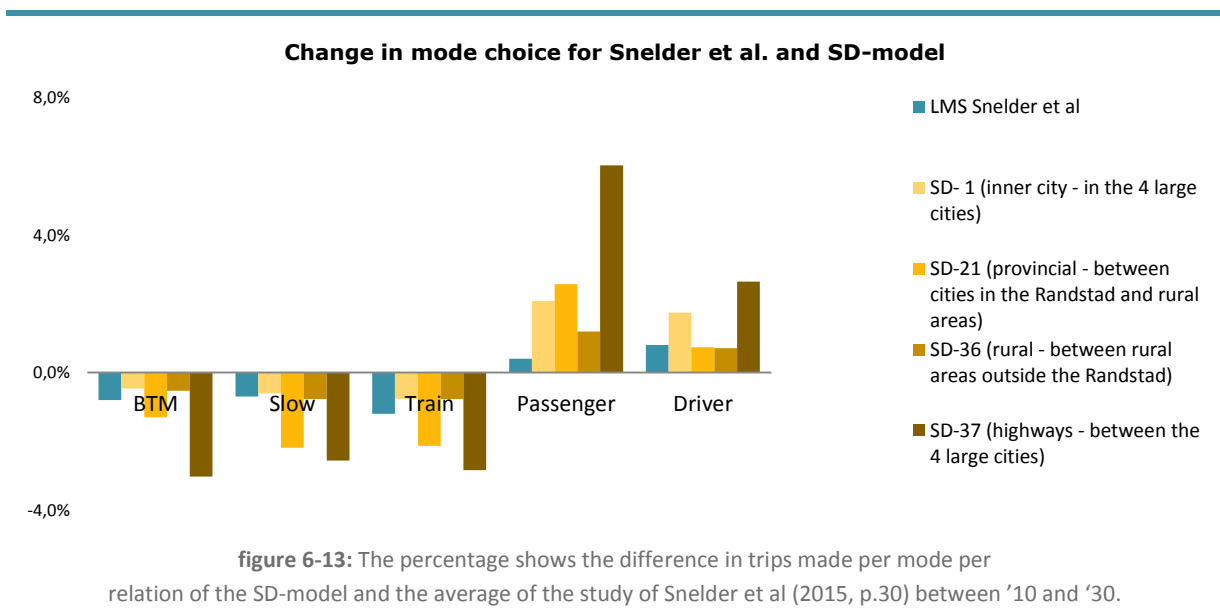## The SD-model compared with LMS with automated vehicles (Snelder et al.)

Snelder et al. (2015) have done an explorative study to simulate the effects of automated vehicles by using a macroscopic model of the Netherlands, the LMS.

Set-up

Snelder et al. use the LMS to simulate all highways, provincial and the main urban roads in the Netherlands from 2010 until 2030. In total 5 different scenarios are researched, but for this study run 4 is compared, as the inputs can be best translated to SD-model inputs. In this run only the capacity is changed, with +15% on the highways, and +10% on the other roads. For relation 1 (large cities) the PCU is set at 0,.9 (+10%). For the others it is set at 0.88 (mix of +10 and +15%) as trips both pass highways and other roads.

Results

Snelder et al. report on the difference in modal split compared to the base case. For the SD-model a base case and an experimental run are compared, the growth percentages per mode are compared. The results are shown in figure 6-13.

figure 6-13: The percentage shows the difference in trips made per mode per
relation of the SD-model and the average of the study of Snelder et al (2015, p.30) between '10 and '30.

What can be found in figure 6-13 is that the SD relations show a logical pattern. On the relations where literature expects most benefits (the highways), most benefits can be seen. If the SD-model is compared to the LMS, can be seen that that both results are in the same direction, but the magnitude differs. Especially the largest zone (zone 36, 44% of the trips in the Netherlands is in this zone) does not differ that much from the LMS. That zone 37 shows a larger shift towards the car modes (driver and passenger) is also logical as this is a relation, which is expected to benefit most from automated vehicles.

However, two aspects are striking: the larger sensitivity and a stronger growth in passengers than in drivers. The higher sensitivity has two reasons. First, due to the calibration method the model has too low constants and too high sensitivity parameters (explanation in textbox 2). Secondly, the capacity in inputs of the LMS are taken over directly. However, the capacity in the SD-model differs

from the capacity in the LMS. In the LMS travel times are not only influenced by the capacity of a road, but also by spillback of congestion or travel time losses at intersections.

The second point, the strong growth in passengers, can be explained by a higher sensitivity for changes of the passengers. This can also be seen when the sensitivities of the LMS and the SD-model are compared in chapter 6.2.

The SD-model compared with the Danish OTM 6.0 (Tetraplan)

Tetraplan is an independent consultant in the field of transport planning and modelling. They perform modelling studies in Denmark and Sweden. An explorative study to the effects of "Selvkørerende biler" (automated vehicles) in the Copenhagen region was done by Chirstan Würtz and his colleagues (Tetraplan 2015).

Set-up
Tetraplan preforms multiple runs in their research: a base run, a run with 30% extra capacity, a run where travel costs decrease with 20%, a run with 50% less parking costs and a run for all effects together. They also tried to perform a value of time run, which led to odd results. From these runs the only run that can be compared is the 30% extra capacity.

Results
In figure 6-14 the SD-model is compared to the OTM. For the SD-model relation 1 is used, as these are trips in the four large cities in the Randstad, so also inner city trips.
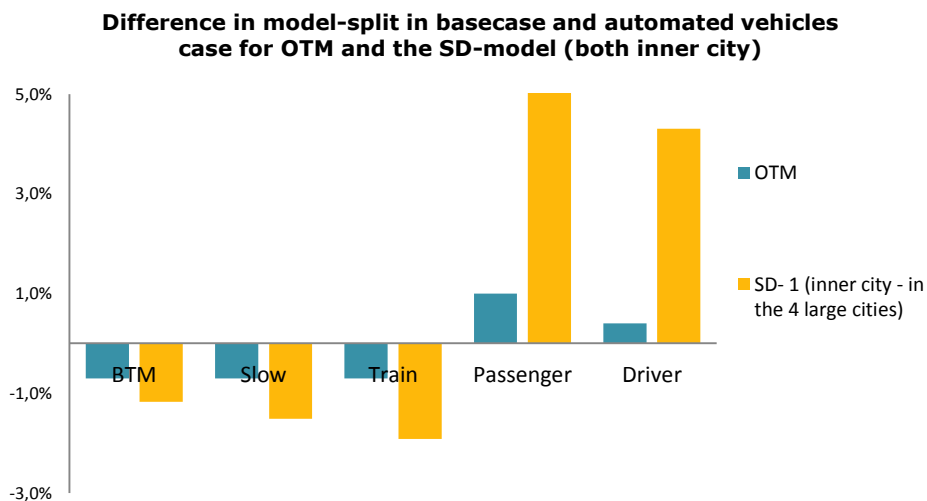

figure 6-14: comparison of the SD-model and the Danish OTM. For both a capacity growth of 30% is simulated.

What can be seen is that the SD-model has a larger change in modal split than the OTM. The ratio of the different modes however is comparable. This mismatch in modal split has the same two reasons as mentioned in the previous paragraph of the LMS: the model seems to be calibrated too sensitive and the capacity effects are modelled different. The capacity effect is even stronger in this comparison. In the OTM the capacity of the roads is enlarged with 30%, but the traffic lights are set the same as in the base run (Vuk et al. 2009; Tetraplan 2015). In urban areas traffic lights however mainly determine the capacity. Therefore, the results are hard to compare.

The two models are be hard to compare due to the different capacity set-ups, but still a comparison can be made. The comparison shows for that modelling urban environments the inputs of the SD-model are more complicated than for highways. In urban environments more factors play are role, such as loss time due to traffic lights.

Another difference is that in the OTM the amount of passengers rises almost double the amount of the drivers, where the LMS predicts more drivers. Although the LMS simulates different relations it seems that the world of modelling automated vehicles has no common view on this aspect.

The SD-model compared with Travel Model One (Gucwa)

Gucwa (2014) started his PHD-thesis, but unfortunately did not finish it yet. He has done simulations of automated vehicles in different scenarios for the Bay Area of San Francisco. The results he gathered so far, are useful to compare to the SD-model.

Set-up

The model study of Gucwa is performed with MTC's *Travel Model One.* This model is used to simulate the San Francisco Bay area. This area consist of a few large cities with San Francisco and San Jose as most well-known. The area is comparable to the Randstad in the Netherlands, both the surface as the amount of inhabitants roughly are the same. The model uses an Activity Based Approach and is the main tool for simulation studies in the area (Gucwa 2014). Self-driving cars are modelled the same way as is done by Snelder et al. (2015) and the Tetraplan (2015): by changing the capacity or/and the value of time for all cars.

Gucwa simulates different scenarios. The scenario where the value of time is half of a normal car and the capacity is 10% higher is best to compare with a run of the SD-model. In the SD-model 100% level 3 vehicles are simulated with a ½ value of time and a PCU of 0.9 (10% less than normal vehicles).

Results

The only output indicator Gucwa shows is the amount of vehicle kilometres driven (both cars and trucks). The difference with the base case in percentage is compared with the same indicator for the SD-model. The results are shown in figure 6-15.

Difference in VKT growth in base case and automated vehicles for Gucwa and the SD-model
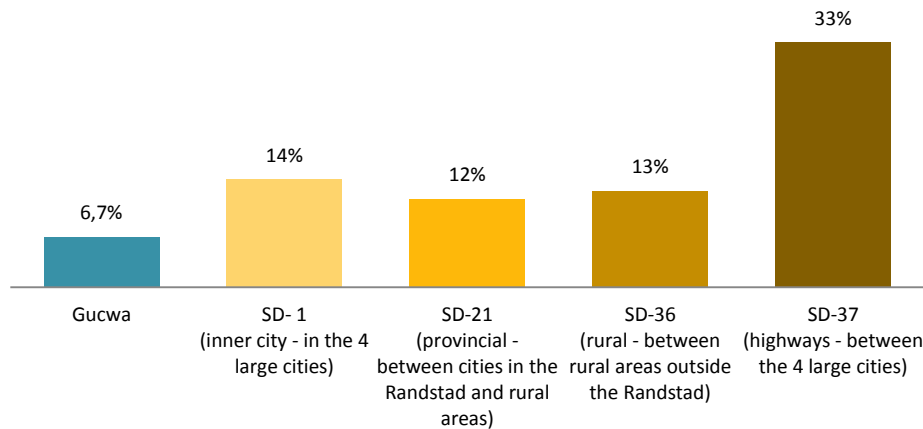

figure 6-15: The percentage shown is the extra amount of vehicle kilometres travelled (VKT) by car and truck for both the model of Gucwa (2014, p.51) and the SD-model of this research.

The SD-model should be compared mostly to the first three relations, as these are most comparable to the Bay Area (relation 37 is intercity). Just as in the study of the OTM and the LMS again the SD-model is more sensitive in the mode choice. The reason for that is that the capacity is determined in another way and the SD-model is too sensitive. However, also Gucwa explains his own results are "rather mundane" (in an e-mail) With which means that his model was less sensitive than expected.

Findings on comparison SD-model and other automated vehicle models

First of all should be said that comparing two models is hard, especially as none of the models has the same network, way of programming or way of simulating automated vehicles. As Snelder, Gucwa and Tetraplan only report about the mode choice or related variables, only the mode choice can be compared. From the tests it can be concluded that in the SD-model automated vehicles lead to larger changes in mode choice than the other models. This has two reasons, first the mode choice is more sensitive than in other models (see textbox 2 or chapter 6.2), Besides that, the capacity in the SD-model has another input than the other models. In other models the travel time is not only based upon capacity, but also on spillback or loss time of traffic lights. The SD-model only takes capacity into account. Still it can be concluded that a rather simple model can simulate effects which are in line with more complex models.

6.7. Is the model valid for its purpose

The goal of the model is to make an explorative model for the mobility impacts of level 1, 2 and 3 in the Netherlands for 2050. The test in this chapter indicate what the strong points are of the model and what can be improved.

Strong points of the model

The strong points of the model are that the structure of the model is grounded in literature and meets the proposed goal. The boundaries and time horizon of the model are logical. The extreme value tests shows that it meets basic physical laws and can be used under normal, but also mildly extreme conditions. The sensitivity test shows normal sensitivities, but when the model is compared to other models the mode choice of the model seems to be somewhat too sensitive. Nevertheless

are the results of a back-cast and a forecast for exogenous data are quite similar to OViN data. In addition, the comparison with other models for automated vehicles show logical results and indicate that a simple model can give results which are in line with three more complex models

Improvements
There are a few improvements for the model, some which are quite easy to implement and others which change the structure and nature of the model.

Most flaws of the model come down to the absence of an explicit network. That the model is not able to simulate all capacity effects, has a too basic assignment and has to make use of an overlap factor are all caused by this shortcoming. Still, it is not advised to make use of an explicit network as that harms the explorative nature of the model. The run time and ease of exploring scenarios and sensitivities would evaporate.

Less intrusive measure to overcome these problems are to make use of different BPR functions in line. By doing this, capacity effects of different road types in line can be simulated more correctly. With multiple BPR functions in the overlap factor becomes more explicit and can be determined with multiple selected link analysis. In such an analysis characteristic roads are researched in another model on different origin-destination pairs. These shares are translated to overlap functions. Using subscripts in Vensim or the new tool Ventity (SD simulation tool specially designed for subscripts, now in beta) for each relation makes it possible to simulate 42 relations at once. Then the overlap factor can be made dynamic.

Another point of attention is the sensitivity of the mode choice. The model is somewhat more sensitive than the LMS, but these effects will be small as a sensitivity analysis shows (see section 6.2). This can be improved by recalibrating the model. Difficult aspect is that it is hard to say when the sensitivities are right. The model can be calibrated to other models, but to what extend do these models simulate reality. Calibrating to the separate years of OViN seems more preferable, however, then many years are needed.

FINDINGS VALIDATION
There is room for improvements but it can be concluded that the model can be used to explore the impacts of early forms of automated vehicles in the Netherlands.

7 Experiments with the model

Previous chapters present the structure of the SD- and show that tests indicate the model is suitable for explorative research. This chapter shows the setup and the results of experiments with the model. The same two environments as in the test phase are used: the lab environment and the real world environment. In the lab environment, the base year is only changed by the introduction of self-driving vehicles. In the real world environment, also other factors influencing mobility are taken into account. First, the lab environment simulations are shown, followed by the real world simulations. Both are done for the two development paths: autonomous and cooperative driving. In the autonomous development path cars only observe the driving environment, in the cooperative path they also communicate with infrastructure and other cars. This gives the ability to platoon with other vehicles. The exact model inputs are shown in table 7-1.

table 7-1: Overview of the diffusion and the 3 aspects which are changed for automated vehicles. Cooperative vehicles have extra benefits above 40% penetration rate as they have the ability to platoon. Table is a copy of table 5-1.

Road type		Autonomous	Cooperative	
Diffusion of automated vehicles				
All levels		Graph from research Nieuwenhuijsen (2015)		
Value of time				
Level 0	all	100%		
Level 1 & 2	all	100%		
Level 3	Inner city	100%		
	Rural / provincial	90%		
	Between cities	80%		
PCU (capacity)				
Level 0	all	1	1	
Level 1 & 2	Inner city	1	1	
	Rural	1	1	
	Provincial	1	1	
	Between cities	1	[0-40%]	1
			[40-100%]	Decrease till 0.95
Level 3	Inner city	0.95	0.95	
	Rural / provincial	1	[0-40%]	1
			[40-100%]	Decrease till 0.95
	Between cities	1	[0-40%]	1
			[40-100%]	Decrease till 0.9
Fuel economy				
Level 0		1	1	
Level 1 & 2		0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85
Level 3	Inner city	0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85
	Rural & provincial	0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85
	Between cities	0.95	[0-40%]	0.95
			[40-100%]	Decrease till 0.85

7.1. Simulations for the lab environment

In the lab environment the external (exogenous) factors do not change over time. This means that the world stays like 2013, except for the gradual introduction of automated vehicles. This is simulated for two development paths: autonomous driving and cooperative driving.

In this chapter only the results of the simulation of the trips between the four large cities in the Netherlands are shown (relation 37). This is done as the main interest of the national government is on highways. In the appendix F the other three relations are shown.

Output indicators

For the simulations five output parameters are used. Most of them are also used in the test setting, but two of them are new and will be discussed briefly:

1. *Average speed of a trip by car (km/h)*
   The output of the BPR assignment function is an average speed on the road. This is presented in this parameter. This is the average speed for the whole trip

2. *Car trips during peak hours[%]*
   The result of the time of day choice logit is the amount of car trips that is made during peak hours (7:00-9:00 & 16:00-18:00). This is shown as a percentage.

3. *Modal split [# trips]*
   The amount of people that travel by a certain mode is the output of the mode choice.

4. *Loss hours corrected for value of time [€]*
   The regular traffic loss hours are the difference between the free-flow speed and the actual speed times the amount of vehicles driving during peak hours. For this indicator this is done per vehicle category and multiplied with their value of time.

5. *Average speed on a relation [km/h]*
   This is the average speeds of all modes on that relation. This indicator is a measure for the mobility or accessibility of a region. This a similar indicator as is argued by Hoogendoorn-Lanser et al. (2012) as new accessibility index.
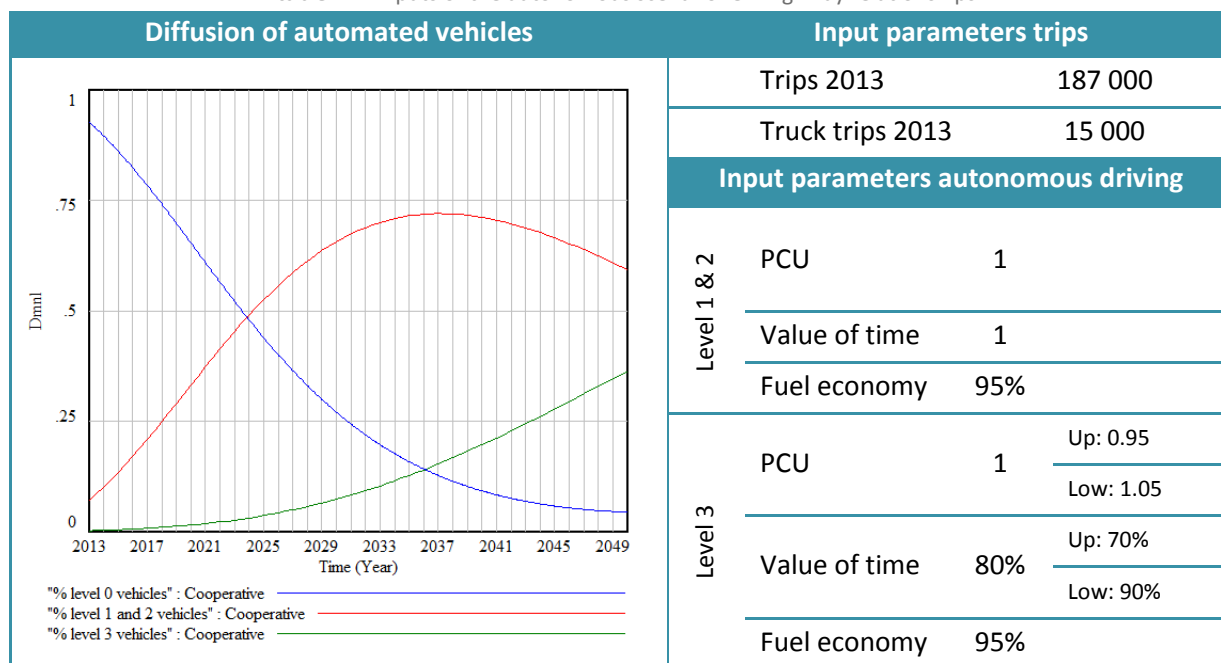
Upper and lower bounds

For different variables upper and lower bounds are discussed in chapter 5 (the model structure for automated vehicles). Not only the base case, but also these upper and lower bounds are simulated. To do so, 2000 runs are simulated with a uniform distribution between the bounds. Also the base case is simulated to be able to make a comparison. These bounds are only shown in graphs where one variable is shown, as Vensim does not give the ability to simulate multiple sensitivity functions in one graph.

Autonomous driving in the lab environment

Set-up autonomous driving

For automated vehicles three parameters are changed: the value of time, the PCU (space a car uses on the road) and the fuel consumption. A total overview of the input parameters for the simulations are shown on in table 7-1 at the start of this chapter.

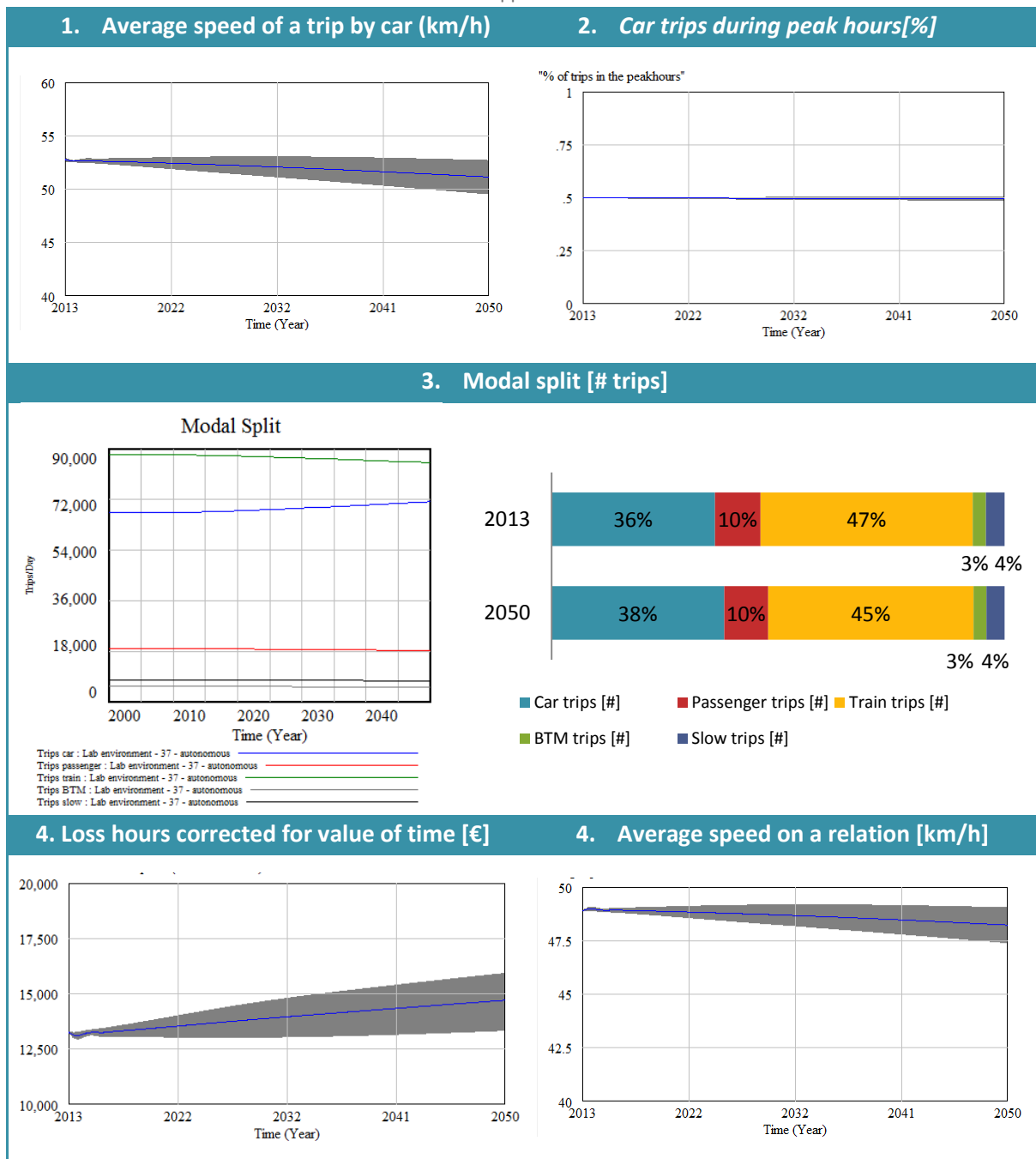**table 7-2:** Inputs of the autonomous scenario. On highway relationships.

Diffusion of automated vehicles		Input parameters trips		
		Trips 2013		187 000
		Truck trips 2013		15 000
		Input parameters autonomous driving		
	Level 1 & 2	PCU	1	
		Value of time	1	
		Fuel economy	95%	
	Level 3	PCU	1	Up: 0.95
				Low: 1.05
		Value of time	80%	Up: 70%
				Low: 90%
		Fuel economy	95%	

Results autonomous driving

The simulations are performed on relation 37 which are trips between the 4 large cities of the Netherlands.

table 7-3: Results of simulations for the autonomous development path. The percentages are the difference with 2013.

	2013	2050		Bounds
Average speed cars [km/h]	53	51 [-4%]	Up	53 [0%]
			Low	49 [-8%]
Average speed on a relation (all modes) [km/h]	49	48 [-2%]	Up	49 [0%]
			Low	47 [-4%]
Trips during peak hours [%]	50	49 [-1%]	Up	51 [2%]
			Low	48 [-4%]
Car trips [#]	67510	71270 [6%]	Up	73120 [8%]
			Low	69100 [2%]
Passenger trips [#]	18910	18240 [-4%]	Up	17900 [-5%]
			Low	19200 [2%]
Train trips [#]	87830	85130 [-3%]	Up	83600 [-5%]
			Low	86400 [-2%]
BTM trips [#]	5480	5298 [-3%]	Up	5200 [-5%]
			Low	5400 [-1%]
Slow trips [#]	7726	7517 [-3%]	Up	7350 [-5%]
			Low	7630 [-1%]
Loss hours on the road [h]	88730	107600 [21%]	Up	122000 [39%]
			Low	91000 [3%]
Loss hours on the road (VOT corrected) [€]	13240	14850 [12%]	Up	16200 [22%]
			Low	13200 [0%]

table 7-4: the results of autonomous driving. The figures only show the outcomes of relation 37. Other relations are in appendix F.

1. Average speed of a trip by car (km/h)	2. *Car trips during peak hours[%]*

3. Modal split [# trips]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]

The outcomes and figures of the other relations are shown in appendix F. On the next page the average speeds and loss hours, corrected for value of time, are shown for all four relations.

table 7-5: The average speeds [km/h] of car trips in peak hours on all 4 relations.

Average speed on relation 1	Average speed on relation 21

Average speed on relation 36	Average speed on relation 37
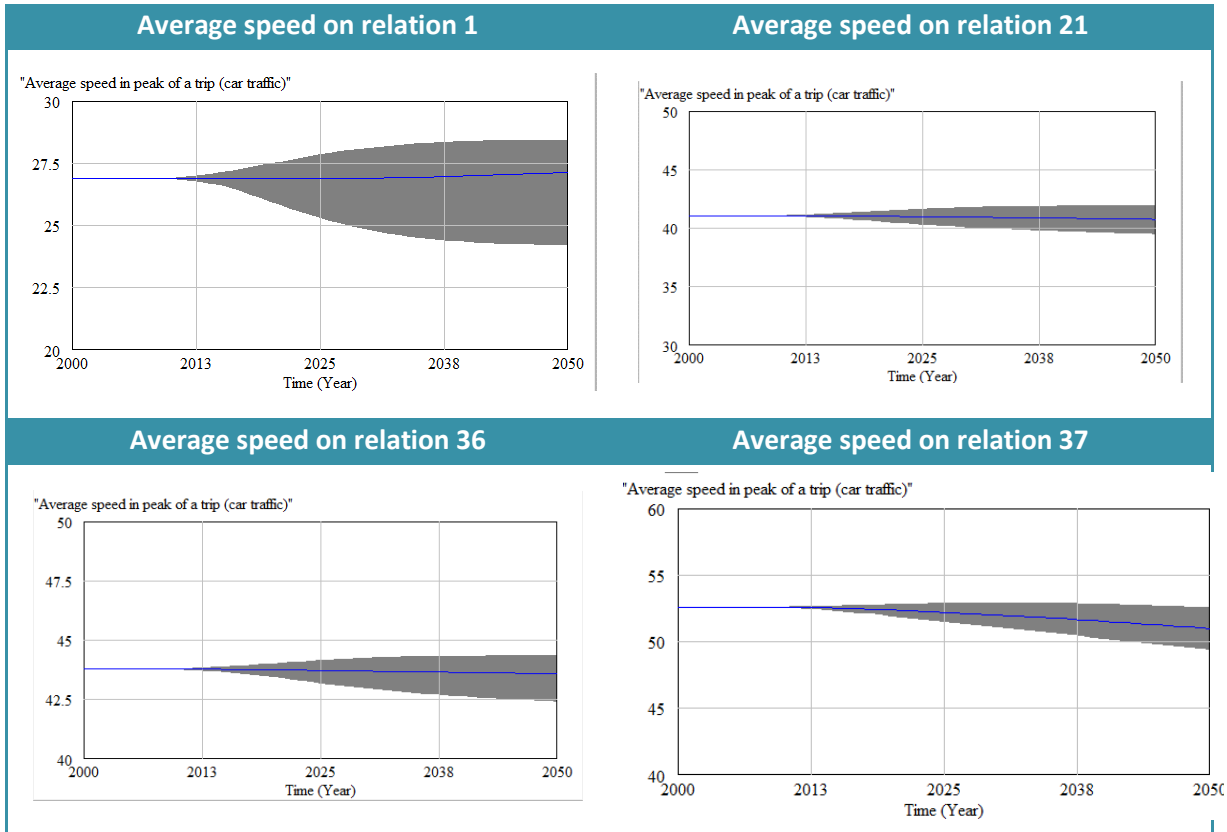
table 7-6: The loss hours of cars in one peak hour corrected for a lower value of time [€] for level 3 vehicles on all 4 relations.

Loss hours (VOT corrected) on relation 1	Loss hours (VOT corrected) on relation 21

Loss hours (VOT corrected) on relation 36	Loss hours (VOT corrected) on relation 37
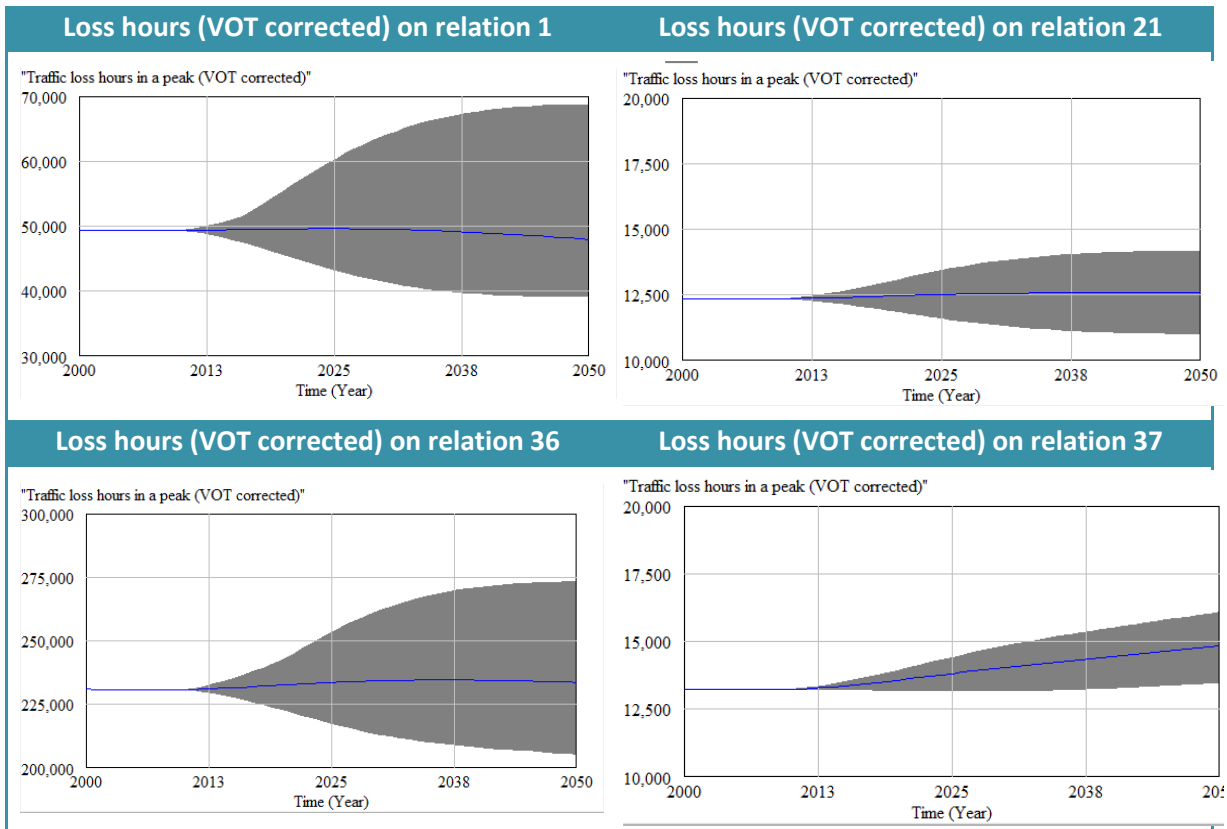
A more attractive car, more vehicles on the road
In table 7-3 and table 7-4 the results of autonomous driving on relation 37 are shown. In this section not only the results of this relation, but also of others are discussed. These are shown in appendix F. For almost all relations the amount of trips made by car are rise in the base case. The effects are the largest on the highways (relation 37) and the smallest in the large cities (relation 1). All other modes lose share, also car passengers.

Speeds drop and more congestion arises
More vehicles on the road can be a sign of more mobility. In the cities, in rural areas and on provincial roads the effects of automated driving are small. Especially as here the value of time effects are smaller. On these three relations the average speed of a relation is expected to be the same, or to stay the same.

On highways between the four large cities in the Randstad (relation 37) the effects are larger. Here more vehicles do not lead to more mobility. On this relation the average speed (average of all modes) decreases. Other indicators also show that due to more vehicles on the road more congestion arises. Only in the most beneficial simulation the average speeds of car traffic in peak hours will stay the same. In all other cases autonomous driving leads to lower average speeds of car trips and therefore for to more congestion. The amount of loss hours will rise, also if this is corrected for the change in value of time. Due to more vehicles and more congestion also the amount of CO_2 emissions is likely to rise. Extra car traffic can be a sign of more mobility, but as the average speeds on the relation (all modes) drop, this is not the case.

Both upside and downside potential in cities, on rural roads and provincial roads
The bandwidths of the relations in cities, rural roads and provincial roads have bandwidths with positive effects or negative effects. The differences can be large, especially in the cities. From 2020 on the differences between these two scenarios (upper bound and lower bound) are large.

Almost only downside potential on highways
In the base case all mobility performance indicators of relation 37 (highways) show a negative outcome. The only benefits on this relation are for automated vehicles users. They can work or relax in the vehicle, where the total travel time of car trips increases. In addition, inspection of the bandwidths shows mainly negative effects. In worst case scenario the speeds drop with 8%, which leads to a 7 minute longer trip from Rotterdam to Amsterdam.

FINDINGS AUTOMATED DEVELOPMENT PATH
Simulations for the autonomous development path show that for trips in large cities, on rural roads and provincial roads (relation 1, 21 and 36) in the base case no large changes are forecasted. Bandwidths however show a positive and a negative scenario. Especially in cities this differences is large.

On highways (relation 37) there is a different result. Here more congestion arises. Due to more vehicles on the road, the CO_2 emissions and other greenhouse gasses are also likely to rise. The only benefits the simulations of autonomous vehicles show are personal benefits for the owners.

Cooperative driving in a lab environment

Cooperative vehicles have a different value of time, PCU and the fuel consumption than normal vehicles. Difference with the autonomous vehicles is that they can form platoons, which leads to extra capacity and fuel benefits, this can only be done after 40% penetration rate. This percentage is reached in 2021. The inputs of the simulation can be seen in table 7-7.

table 7-7: Inputs of the cooperative scenario. On highway relationships.

Diffusion of automated vehicles	Input parameters trips		
	Trips 2013	187 000	
	Truck trips 2013	15 000	
	Input parameters cooperative driving		
	PCU [0-40%]	1	
	PCU [40-100%]	0.95	Up: 0.8 Low: 1
	Value of time	1	
	Fuel economy	95%	
	PCU [0-40%]	1	
	PCU [40-100%]	0.9	Up: 0.7 Low: 1
	Value of time	80%	Up: 70% Low: 90%
	Fuel economy [0-40%]	95%	
	Fuel economy [40-100%]	85%	

Left column rows labelled "Level 1 & 2" (PCU [0-40%], PCU [40-100%], Value of time, Fuel economy) and "Level 3" (PCU [0-40%], PCU [40-100%], Value of time, Fuel economy [0-40%], Fuel economy [40-100%]).

Graph legend:
"% level 0 vehicles" : Cooperative
"% level 1 and 2 vehicles" : Cooperative
"% level 3 vehicles" : Cooperative

table 7-8: Results of simulations for the autonomous development path. The percentages are the difference with 2013.

	2013	2050	Bounds	
Average speed cars [km/h]	53	52 [-1%]	Up	57 [8%]
			Low	49 [-8%]
Average speed on a relation (all modes) [km/h]	49	49 [0%]	Up	52 [6%]
			Low	47 [-4%]
Trips during peak hours [%]	50	50 [0%]	Up	53 [6%]
			Low	48 [-4%]
Car trips [#]	67510	73490 [9%]	Up	77500 [15%]
			Low	72000 [7%]
Passenger trips [#]	18910	17850 [-6%]	Up	18100 [-4%]
			Low	17400 [-8%]
Train trips [#]	87830	83550 [-5%]	Up	85200 [-3%]
			Low	80100 [-9%]
BTM trips [#]	5480	5191 [-5%]	Up	5300 [-3%]
			Low	4950 [-10%]
Slow trips [#]	7726	7394 [-4%]	Up	7520 [-3%]
			Low	7150 [-7%]
Loss hours on the road [h]	88000	100000 [14%]	Up	64000 [-27%]
			Low	15700 [18%]
Loss hours on the road (VOT corrected) [€]	13250	13754 [4%]	Up	9120 [-31%]
			Low	15700 [18%]

Results: cooperative driving

table 7-9: the results of cooperative driving. The figures only show the outcomes of relation 37. Other relations are in appendix F. In 2021 there is 40% penetration rate of cooperative vehicles.
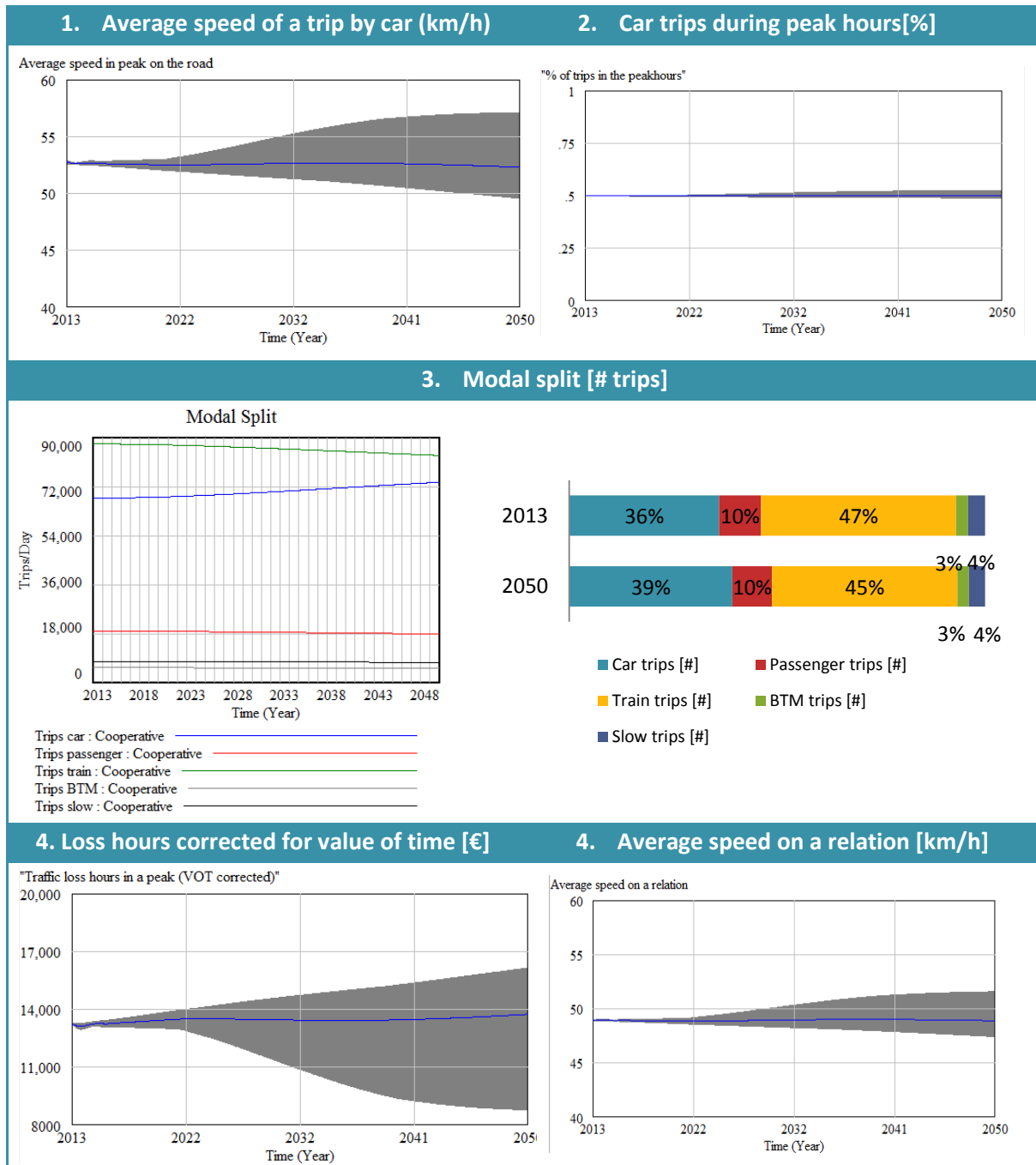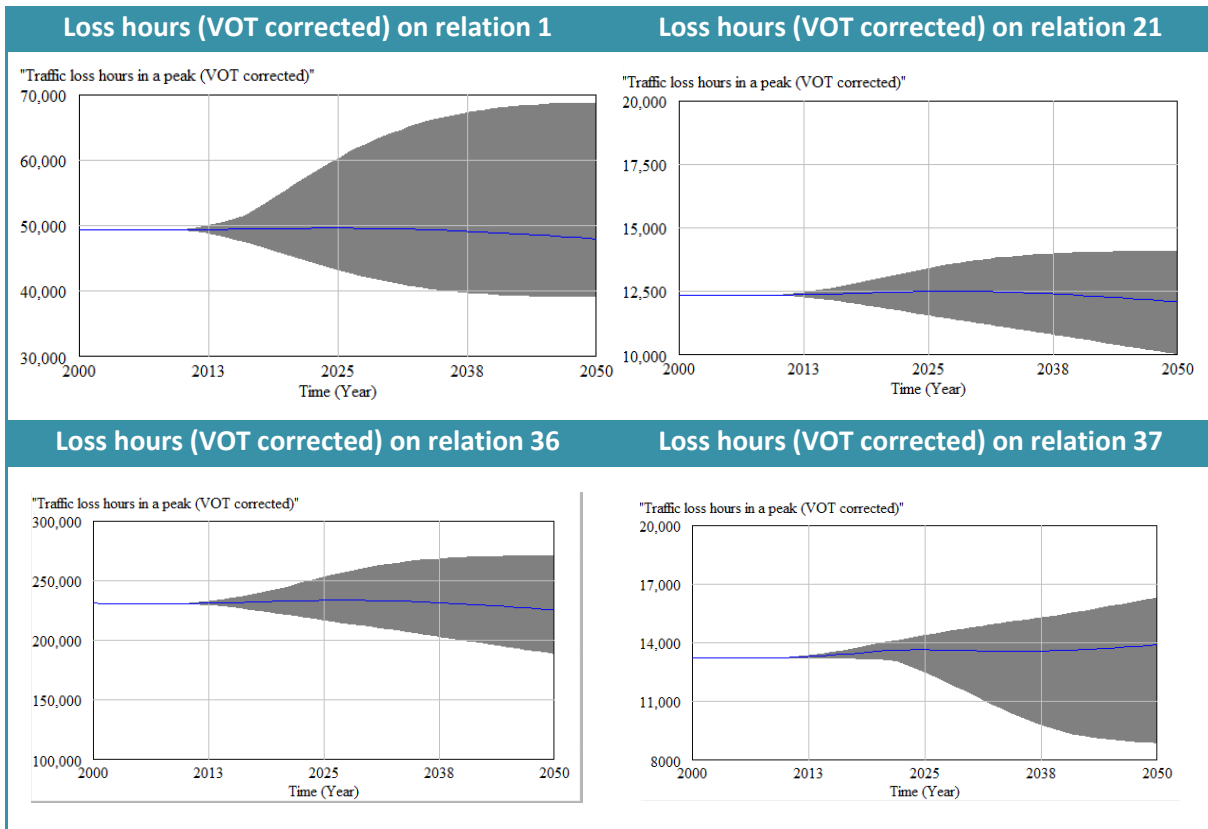
1. Average speed of a trip by car (km/h)	2. Car trips during peak hours[%]

Average speed in peak on the road

"% of trips in the peakhours"

3. Modal split [# trips]

Modal Split

Trips/Day

Trips car : Cooperative
Trips passenger : Cooperative
Trips train : Cooperative
Trips BTM : Cooperative
Trips slow : Cooperative

| 2013 | 36% | 10% | 47% | 3% 4% |

| 2050 | 39% | 10% | 45% | 3% 4% |

■ Car trips [#] ■ Passenger trips [#]
■ Train trips [#] ■ BTM trips [#]
■ Slow trips [#]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]

"Traffic loss hours in a peak (VOT corrected)"

Average speed on a relation

table **7-10**: The average speeds [km/h] of car trips in peak hours on all 4 relations.

Average speed on relation 1	Average speed on relation 21
Average speed on relation 36	Average speed on relation 37

table **7-11**: The loss hours of cars in one peak hour corrected for a lower value of time [€] for level 3 vehicles on all 4 relations.

Loss hours (VOT corrected) on relation 1	Loss hours (VOT corrected) on relation 21
Loss hours (VOT corrected) on relation 36	Loss hours (VOT corrected) on relation 37

More vehicles on the road

Not only the results of relation 37, but also the relations shown in appendix F are explained here. The figures make clear that in the cooperative development path the car gets more attractive, just as in the autonomous path. This holds for all relations. On the highway relation (37) this is the strongest (9%) where the other three relations grow more mildly (1 or 2%). Not only a lower value of time, but also fuel economy advantages lead to a higher utility for car users. All other modes lose share, also car passengers. The amount of car trips made during peak hours roughly will be the same.

Average speed stays roughly the same

Due to more vehicles on the road the average speeds on the roads are likely to drop, however, cooperative vehicles have extra capacity benefits above 40% penetration rate. Due to these benefits the average speeds will roughly stay the same. As a result of more vehicles on the road the amount of loss hours will rise. Because on highways the value of time benefits are the largest are here the effects the biggest. If the loss hours are corrected for the lower value of time of level 3 vehicles the economic loss of these hours will roughly stay the same over time. This holds for all relations. Due to more car trips made and more congestion the amount of CO_2 emissions will rise. The same will hold for other emissions, unless changes are made to vehicles to make them more sustainable.

Both upside and downside potential

For relation 1 (inner city trips in the 4 large cities) the bandwidths are large. Here the uncertainty of impacts is the highest. Loss hours (corrected for VOT) differ 20% down or 30% up. In all other relations this uncertainty is smaller. In most cases, and especially on the inner city and highway relation the upside potential of cooperative vehicles is larger than the downside potential. Especially the upside potential of level 1 and 2 vehicles is higher than their downside potential. For level 3 vehicles this is roughly the same. This means that in 2050 on average there is the same bandwidth up and down. In the most beneficial case the speeds of car trips will rise with 8% on the investigated highway relation. This means that a trip from Rotterdam to Amsterdam takes 7 minutes less in a peak hour, which is a significant change. However, the downside potential is a 7 minute longer trip.

FINDINGS COOPERATIVE DEVELOPMENT PATH

The effect of automated vehicles in the inner city relation, the rural relation and the provincial relation are small. Automated vehicles will lead to a small increase in car trips, and a decrease on all other modes. Bandwidths are relatively small and mainly positive,. For inner city traffic the bandwidths are somewhat greater, here the loss hours can differ at least 20% up or down.

On the highway relation 9% extra car trips are forecasted. The simulations indicate that cooperative automated vehicles will lead to more car traffic and a little more congestion. Capacity advantages of cooperative driving neutralise the effect of extra cars, but do not lead to less congestion. Due to more vehicles on the road the emissions of CO_2 and other greenhouse gasses are likely to rise. The average speed on the relation will on all investigated relations stay the same.

7.2. Simulations for the real world environment

Besides the lab environment, where no other aspects change besides the introduction of automated vehicles, also other changing variables are taken into account. In this set-up is aimed to model the most important factors which influence mobility until 2050. The factors are shown in table 7-12.

table 7-12: Overview of the changing parameters for the real world scenario. This table is a copy of table 4-4.

What	Change per year	Source
Population growth	Between 0,1% and 0,4%	PBL (2013)
More car ownership	0,2 %-point extra cars available	LMS assumption (Ministerie van Infrastructuur en Milieu 2015)
Higher PT costs /km	0,5% extra €/km	
Decrease car costs / km	0,7% less €/km	
More trucks	1,4% extra trucks	
Faster trains	0,3 minutes *(between '17 and '30)*	Program High Frequency Rail (Mansveld 2014)
Extra road capacity	Between 0,8% and 1,3% extra	Assumed based upon highway expansion between '14-'17 (Rijksoverheid 2015)
Introduction of Automated vehicles	Introduction graph	Nieuwenhuijsen (2015)

The simulations for the real world are done for a base case and the two experimental development paths: cooperative and autonomous driving. Results simulations of the two development path and the base case.

table 7-13: Inputs of the cooperative scenario. On highway relationships.

Diffusion of automated vehicles		Input parameters trips		
		Trips 2013		187 000
		Truck trips 2013		15 000
		Input parameters	Cooperative	Autonomous
	Level 1 & 2	PCU [0-40%]	1	1
		PCU [40-100%]	0.95	
		Value of time	1	1
		Fuel economy	95%	95%
	Level 3	PCU [0-40%]	1	1
		PCU [40-100%]	0.9	
		Value of time	80%	80%
		Fuel economy [0-40%]	95%	95%
		Fuel economy [40-100%]	85%	

Diffusion of automated vehicles graph. Y-axis: Dmnl (0 to 1). X-axis: Time (Year), 2013–2049.
"% level 0 vehicles" : Cooperative
"% level 1 and 2 vehicles" : Cooperative
"% level 3 vehicles" : Cooperative

Average speed in peak of a trip (car traffic)

Traffic loss hours in a peak (VOT corrected)

Average speed on a relation

Average speed on a relation : Real world - 37 - no automated vehicles ————
Average speed on a relation : Real world - 37 - cooperative ————
Average speed on a relation : Real world - 37 - autonomous ————

figure 7-1: The three most interesting[34] comparisons of the base case and the two development path. The complete mode choice picture can be seen in figure 7-2. All simulations are done for relation 37.

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[34] Time of day choice shows the same of only very mildly different results for the three development path.

Amount of vehicles rises strongly

From the simulations where different factors influencing mobility are taken into account can be seen that the amount of car traffic rises strongly. Where the population rises with only 16% the amount of car traffic rises with 50%. This is also the case for other relations. In all three runs (the cooperative, autonomous and without automated vehicles), this happens. The popularity of the car can thus not only be explained by automated vehicles, but mainly by an increase in costs for other modes and a decrease in car costs. Due to this increase in public transport costs, the share of BTM decreases in percentage terms the most (see figure 7-2).

On the rural, provincial and inner city relation the same patter can be seen. Difference is that the effects are somewhat smaller and the amount of passengers roughly stays the same or increases a little. The figures of all simulations might be somewhat overestimated (see section 6.2) due to a too sensitive mode choice. However, this will only be a few percentage points (see comparison with the LMS or sensitivity runs).

Growth of trips per mode for the different scenarios

Relative growths related to the base case
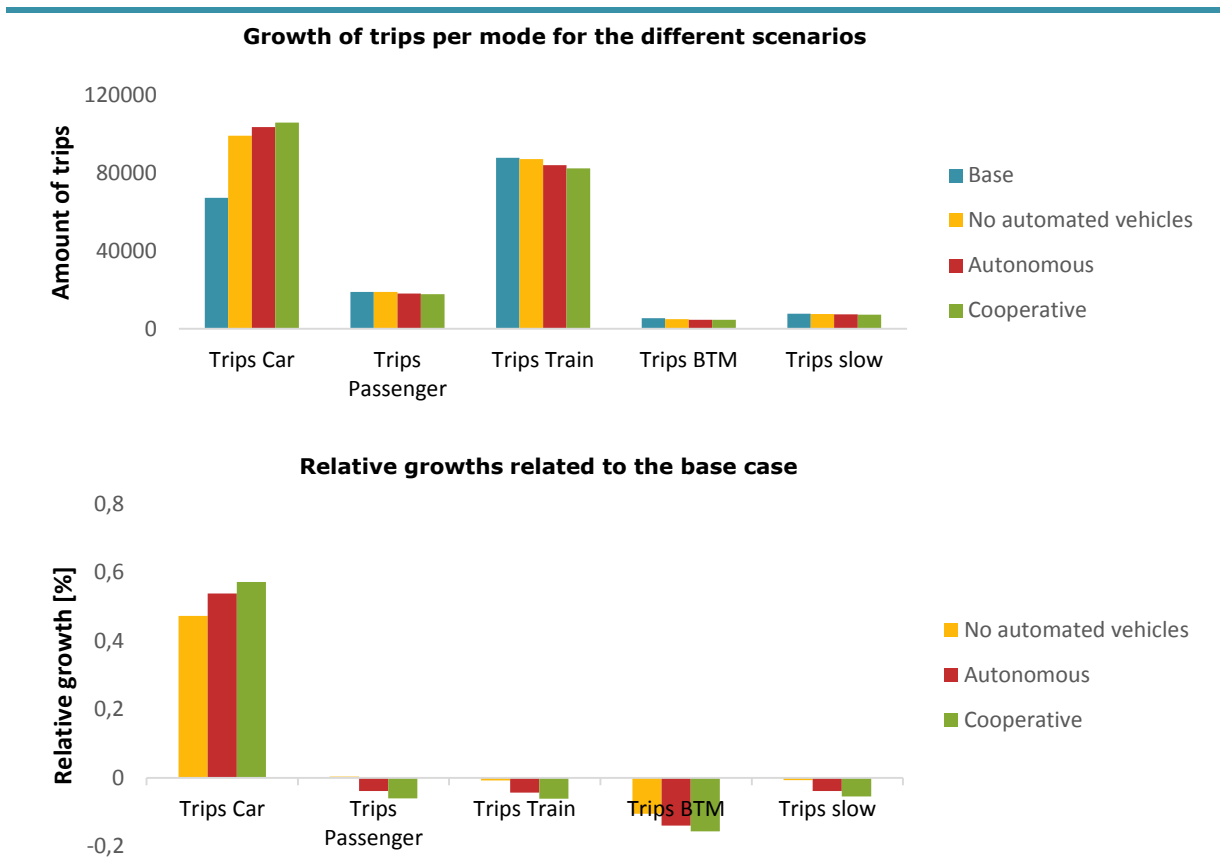
figure 7-2: Difference in mode choice between 2013 and the three scenarios for 2050. The top figure shows the absolutes, the bottom the precentral differences between the base year and the simulated scenario. All simulations are done for relation 37 (trips between the 4 large cities).

Only a slight difference between the scenarios

The three scenarios differ only a few percentage points, until 2025 the results are roughly the same. In 2021 the 40% cooperative vehicle point is reached, therefore cooperative vehicles get more benefits from there on. Still, the three scenarios do not differ much, which means that other factors

influence mobility stronger than automated vehicles do. In 2050 the average speeds of the three different paths only differ 1,5 km/h at maximum.

The scenario without AVs leads to more mobility than autonomous driving
For the average speed of car trips in peak hours, the amount of loss hours and the average speed on a relation the scenario without automated vehicles scores better than autonomous driving. The simulations in the lab environment suggested this and the real world simulations confirm this. The cooperative scenario and the scenario without automated vehicles do not differ that much. There are only tiny differences between the two.

The explorative nature of the simulations
The simulations for the real world depend strongly on the input parameters. Especially the capacity growth is hard to forecast and even harder to translate into parameters for this model. The results therefore show a first insight, but should be seen as explorative. As in all three simulations the same assumptions are made the three scenarios can be compared. Making judgements on the influence of exogenous inputs is therefore not done.

7.3. Alternative expertiments

Besides the experiments in the lab environment and the real world environment some other experiments are done. These experiments gain insights in alternative scenarios and indicate how the model also can be used.

No level three vehicles, only level 1 and 2 vehicles

In this research level 3 vehicles are researched, however, the introduction of level 3 vehicles is disputed. The 'driver' of such a vehicle should be able to take over the wheel within a few seconds, which might lead to dangerous situations. Therefore a run is performed where only level 1 and 2 vehicles are on the road.

Set-up of the simulation
For the simulation the share of level 3 vehicles is added to the share of level 1 and 2 vehicles. This means that in 2050 almost all vehicles will be level 1 and 2 vehicles. The simulation is done in the lab environment, for both the cooperative and the autonomous scenario. Simulations are only performed on relation 37, these are trips between the four large cities of the Netherlands.

Results of the simulation
In figure 7-3 the results of the simulation are shown. It can be seen that only level 1 and 2 vehicles lead to higher average speeds of cars than in the case when level 3 vehicles also are on the roads. This is because level 3 vehicles have a lower value of time, which makes the car more attractive.
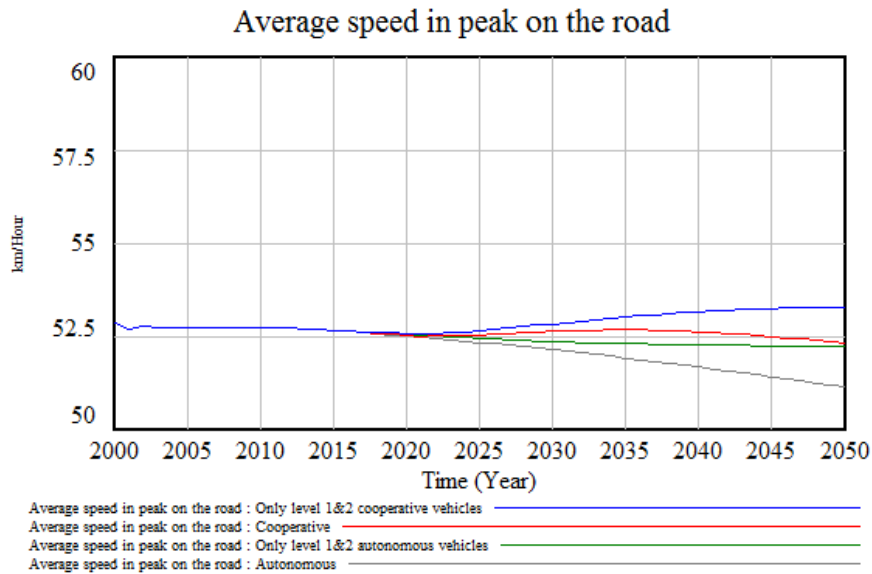
figure 7-3: The graph shows the difference in average speed for simulations for only level 1 and 2 vehicles and also level 3 vehicles.

Mix of cooperative and autonomous vehicles

All simulations done before were only with cooperative or only with autonomous vehicles. However, a share of different vehicle types is most likely to be on future roads. Ten runs are performed with a different share of cooperative vehicles. From these simulations we can obtain insight in the dynamics of shares of vehicles.

Differences between cooperative and autonomous vehicles are that cooperative vehicles can form platoons. This leads to extra capacity and fuel economy benefits after 40% penetration rate.

Results

In figure 7-4 the *loss hours (VoT corrected)* and *average speed of car trips* are shown per penetration rate of cooperative vehicles. It can be seen that speeds only rise and loss hours only drop if there are more than 40% cooperative vehicles. It can be seen that a small share of cooperative vehicles has no effect on the speeds on the road.

Side note: 100% cooperative vehicles does not mean that of the total fleet is cooperative, but that 100% of the level 1, 2 and 3 vehicles in 2050 is cooperative. In 2050 the model assumes 4% level 0 vehicles, 60% level 1&2 and 36% level 3 vehicles.
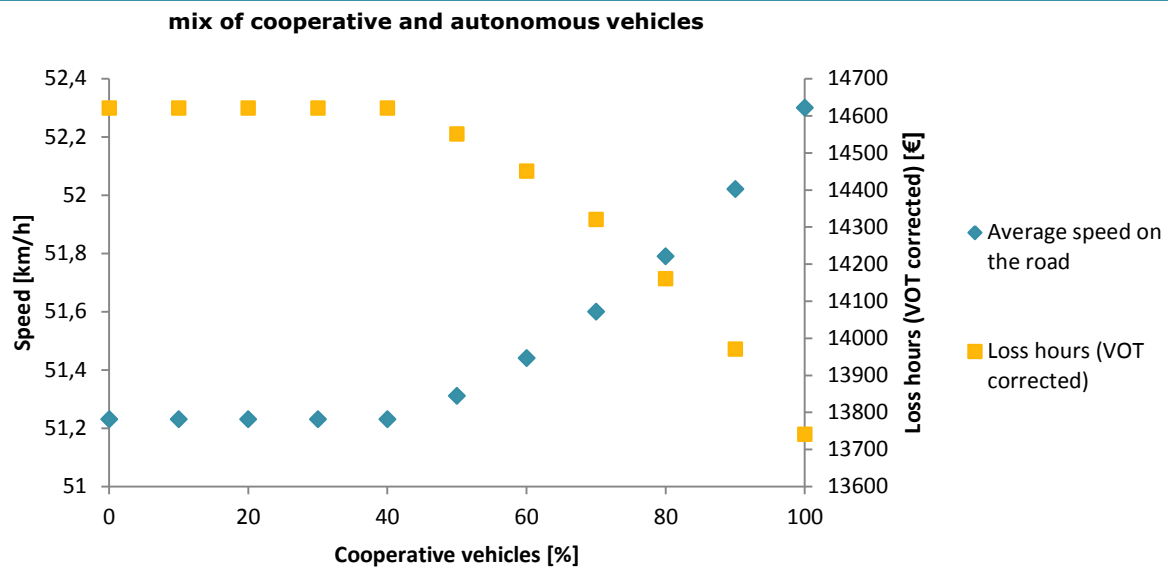
figure 7-4: The graph shows the speeds and loss hours in 2050. The graph shows that only after 40% penetration the effects of cooperative vehicles will have an effect.

All vehicles can be followed by cooperative vehicles

From the simulations it can be concluded that cooperative vehicles lead to more benefits in terms of mobility. In previous simulations cooperative vehicles can only follow other cooperative vehicles. In this simulations is researched what would happen if cooperative vehicles can follow normal vehicles with a smaller headway. This means that the level 0 vehicles also should be equipped with soft- and hardware. Shladover et al. (2012) call these vehicles 'Here I am'-vehicles. In the simulations this means that the 40% threshold does not arise and cooperative benefits arise immediately.

Results

The results of the simulation are shown in figure 7-5. It can be seen that with 'here I am'-vehicles the amount of loss hours during peak is lower than without. Especially between 2015 and 2021 rise less strongly. In these years the first level 3 vehicles are on the road, which lead to extra car traffic due to personal benefits, but the 40% threshold is not reached. After 2021 when this threshold is reached the amount of loss hours for the cooperative path decreases. The simulation with 'here I am'-vehicles does not have such a bump.
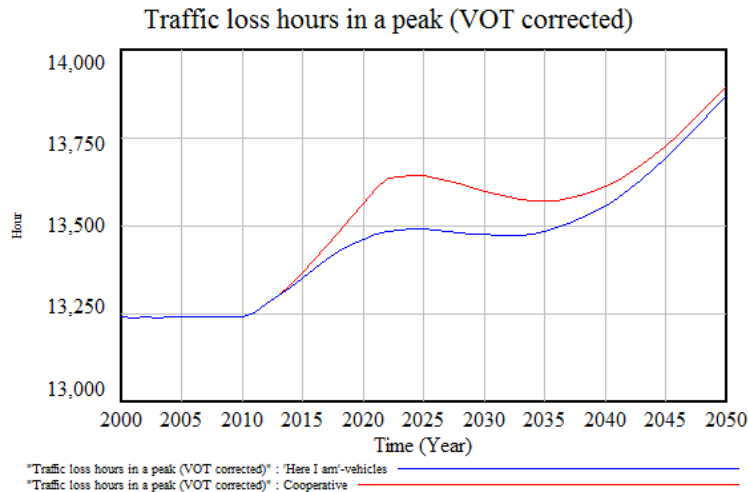
figure 7-5: The red line indicates the amount of loss hours for the cooperative run. In the blue run all vehicles can be followed. The non-automated vehicles are than equipped so they are 'here I am'-vehicles. Both are compared for the lab environment.

At the end of the simulation, in 2050, the difference is small, as there are almost no level 0 vehicles left. The difference in 2050 might be small, but over time there is an mobility advantage due to the 'here I am'-vehicles.

The economic benefits can be calculated with the model. The *integral of the differences between the lines* times *250 working days* times *4 peak hours* a day leads for this relation to savings of around 3 million euro. This is a very small saving compared to the price of equipping all vehicles with such a system. Nevertheless, relation 37 (trips between large cities in the Randstad) is only a 3% of all traffic on highways. If on all highway relations the effect of 'here I am'-vehicles was this large the savings will be around 92 million euro. Probably is this amount of money is still not enough to invest in this technology[35].

Faster introduction of automated vehicles

The diffusion graph used in this research is quite pessimistic. Car manufacturers as Tesla or Google state that in this decade they try to have self-driving cars in stores. Therefore, two other diffusion graphs are investigated for the model. One first is the graph used in this research, the second is the original outcome of Nieuwenhuijsen (2015) his model, the third is a twice as fast introduction. The last graph is also based upon Nieuwenhuijsen his research. All level 4 and 5 vehicles are added to the share of level 3 vehicles. All simulations are done for the cooperative scenario for relation 37.

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[35] This cost benefit analysis is very simplistic, but gives a quick overview. Probably several billions are needed to equip all vehicles in the Netherlands, to research the system and for all overhead costs which come along with them. As the amount of 92 million is not in range with several billions it is not worth researching more in depth.

Results

Table 7-14: On the left three different diffusion graphs. On the right three output indicators for the three diffusion graphs.

Diffusion graphs	Different outputs of the model

Blue is introduction used in this research
Red as Nieuwenhuijsen predicts
Green is twice as fast as Nieuwenhuijsen

Introduction as is used in this research

Average speed in peak on the road

Introduction according to Nieuwenhuijsen

Traffic loss hours in a peak (VOT corrected)

Introduction twice as fast as Nieuwenhuijsen predicts

Trips car

Table 7-14 shows the results of the three simulations. It can be seen that with a faster introduction of the vehicles all effects arise same effects arise, only faster. We can see that if more vehicles are automated more people choose the car as preferred mode of transport and therefore more congestion arises. Especially when the introduction happens twice as fast it can be seen that the car becomes increasingly popular and the average speed of car trips drop and the loss hours rise.

What this simulation also makes clear are extremes when almost every car is a cooperative vehicle. From the simulation where the introduction goes twice as fast can be seen that when 95% of the vehicles is a level 3 cooperative vehicle the amount of vehicles has risen with 18%. Where in the normal introduction graph the speeds roughly stay the same do they also drop in the cooperative scenario.

Effects of capacity on different relations

The simulations performed in 7.1 show effects on different relations with different input parameters. For this investigation the sensitivities of the four relations for the PCU are compared. As in 7.1 was shown that the inner city relation was more sensitive to changes in PCU this will be investigated for all relations.

Set-up of the simulations

In the simulations for different PCU values the loss hours are compared for 0% automation and 100% automation. For the simulations the autonomous PCU is changed. This value is changed from 0.7 until 1.2.

Results

In table 7-15 the results of the simulations are shown. The table shows the sensitivities per PCU value. The same is done, however than in precentral differences in figure 7-6. The graph shows the sensitivities per PCU value. The sensitivities differ per PCU value and are therefore non-linear. This is due to the non-linear shape of the speed-flow curve.

What can be seen is that relation 1, 21 and 36 are more sensitive, and increasingly sensitive. With a 20% PCU rise the loss hours of relation 1 (inner city) and 36 (rural) rise with more than 70%. The rises of the other two relations are less extreme. The difference is explained by the 'urbanisation factor' in the speed-flow curve, this sets the steepness of the curve.

table 7-15: The growths for a 20% higher PCU value and a 30% lower PCU value.

Change in PCU	Observed change in loss hours			
	Relation 1 *In large cities*	Relation 21 *Provincial roads*	Relation 36 *Rural roads*	Relation 37 *Highways*
20%	87490 [177%]	19700 [159%]	397800 [172%]	17020 [129%]
0	49360 [100%]	12360 [100%]	230900 [100%]	13240 [100%]
-30%	17020 [34%]	4096 [33%]	74850 [32%]	6206 [47%]

The simulations show that the urban and rural relations are more vulnerable to automated vehicles which have are harm the capacity. The opposite, if problems decrease fast if automated vehicles have positive capacity effects is not true. From simulations this can be observed, however in urban areas the capacity is determined by traffic lights, which are not simulated in the SD-model.
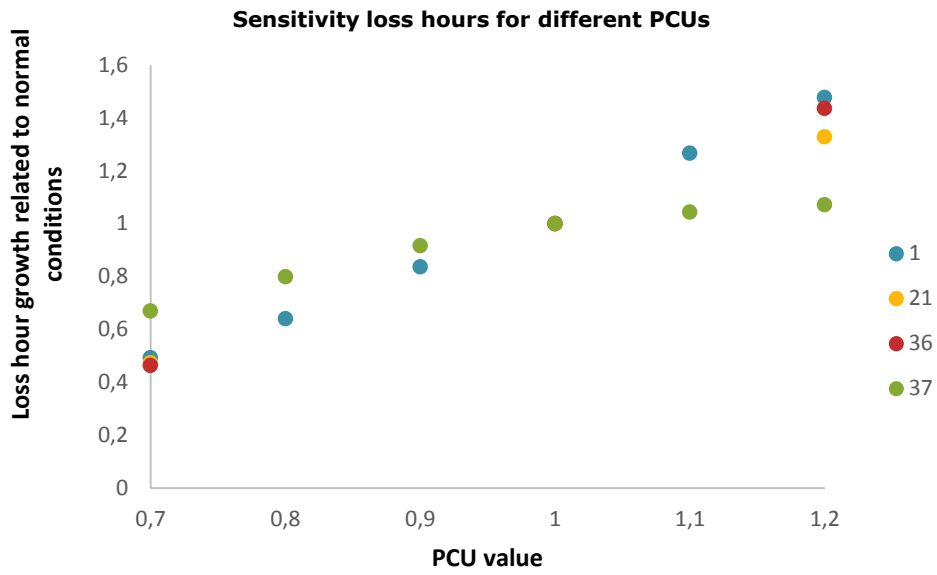
figure 7-6: Sensitivities for different PCU values for the four relations. It can be seen that the sensitivities are non-linear for differences in PCU value. A linear relation would lead to a horizontal graph. This is due to the form of the speed-flow curve.

8 Discussion of the analysis

This chapter will be used to zoom out and to oversee the modelling approach. We will discuss the model in relation to other models, the use of the model and interpret the results from the simulations. As a new model is built for this research and a less likely method is used both the model and the method are discussed. After the discussion of the method the results are interpreted and linked to literature and practice.

8.1. Discussion of the used method

The discussion of the model consists of four steps: the use of System Dynamics as a method, the use of the chosen structure, how automated vehicles are modelled and which data is used.

The use of System Dynamics (SD)
The model makes use of System Dynamics. Especially the explorative nature of the model described in literature was an advantage over macroscopic models. The method has proven itself as being explorative: it gives quick insights for many different scenarios. Where a run of the LMS takes half a day, the SD-model can do 200 runs in one second (for one relation). Compared to System Dynamics literature and other SD models, the model barely makes use of stocks. Due to this, almost no information of t-1 is used to forecast the next time step, only the speed on a relation is fed back. The mode choice and time of day choice are modelled with causal relations, where a more System Dynamic approach would make use of stocks.

The model is set-up similar to a traditional transport model in System Dynamics software, rather than a SD-model for transportation. This makes that traditional transportation elements as a mode choice based upon logits could be used, but that the model does not make use of basic SD constructs.

How the model is built up: all transport
The model is based upon literature from the ScenarioExplorer (Heyma et al. 1999c; Malone et al. 2001) and similar concepts proposed by Horváth (2012). The most important steps of modelling supply and demand of transportation are captured in the model. However, the trip generation and the assignment are simplistic. By doing so, less data is needed and the computational time of the model stays short. However, not all aspects can be captured. The SD-model structure is very suited to make a quick scan for automated vehicles, but for more detailed analysis the model a lot more information is needed. Especially for the assignment more data and other modelling concepts are needed if other policy questions are asked.

Due to the simplifications the model can be used to see the effect of changes in the transportation system without having a high computation time. This makes analysis of many different alternatives and policy scenarios possible.

How the model is built up: automated vehicles
In the model three new concepts for large scale modelling of automated vehicles are tested. First, there are user classes for different levels of automation. These user classes make different choices in the mode choice and time of day choice and have another effect on the capacity in the assignment. For the time of day choice and mode choice the value of time and fuel economy are changed, but

with small modifications more concepts can be added. This model is the only large scale model which can simulate these different user classes for automation in the mode choice, time of day choice and assignment.

Secondly, the way capacity effects of automated vehicles are simulated is new. Where in other models (Gucwa 2014; Snelder et al. 2015; Tetraplan 2015) the capacity of roads is changed, in this model the flows are changed. Especially making the PCU value dependent on the penetration rate is novel. This makes that effects of cooperative driving can be taken into account more realistically, as it is possible to model cooperative effects after 40% penetration rate. The main advantage of using PCUs instead of adapting the capacity is that mixed traffic is easier to take into account, as different types get other PCUs. Mixed traffic can a mix of trucks and cars, a mix of different SAE levels and a mix of autonomous and cooperative vehicles.

Thirdly, with the same concept as the capacity the fuel economy is changed. If the penetration rate of vehicles rises, the fuel economy per cooperative vehicle also rises. By doing this, the fuel advantages of platoons can be simulated.

Nevertheless, not all concepts of early forms of automated vehicles are captured. Spatial effects or effects on trip generation and distribution are not taken into account. Also the effect that people might travel longer distances as their value of times are lower are not taken into account. Appendix G gives suggestions how to model these, and other, new concepts for the model. All uncaptured effects of automated vehicles will lead to more benefits for the car, but not to a higher capacity. Therefore, the speeds on the road are most likely to drop a little more than is shown in the model.

Besides these concepts, not captured in the model, many assumptions were made. The effects automated vehicles have are highly uncertain. Therefore, the outcomes of a single run are not the most important outcome, but the insights in the bandwidths and different scenarios provide are the largest contribution.

Data used as input for the model
For the model OViN data is used to calibrate the mode choice and time of day choice. The data from OViN has its flaws, especially on small zones. Therefore, the data of four years is used summed. Still, the calibration of the mode choice and time of day choice has errors: the mode choice seems to be too sensitive, the time of day choice not sensitive enough. Investigations in show that the differences are small, but present (see section 6.2). All 42 relations are calibrated, however only 4 relations are used. It is expected that the other relations have the same flaws as they are calibrated in one fitting session. For a new version of the model the calibration should be improved. More data sources are needed to fit the data.

Besides OViN data also other data is used. Forecasts for the population growth, new travel times for trains and for prices of car and public transport are used. The growth of the road network is calculated based upon the realised extra roads of the last years. The most important concepts are taken into account, however, several factors are missing. An ageing population for instance. The exogenous parameters leave opportunities for improvement.

8.2. Interpretation of the results

In this research simulations are performed for the two identified development paths: autonomous driving and cooperative driving. This is done for a lab-environment, where no exogenously changing variables are not taken into account and a real world environment, where changing variables such as demographic growth are taken into account. Simulations are performed until 2050.

Automated vehicles lead to more vehicles and more congestion
Where governmental papers (Schultz van Haegen 2014; Department of Transport 2015a), microsimulations (Arnaout & Bowling 2011; van Arem et al. 2006; Shladover et al. 2012) and scientific outlooks (Litman 2014; Snelder et al. 2015; Fagnant & Kockelman 2015) mainly present positive effects of automated vehicles on mobility, this research presents an opposing force. The simulations show that the personal benefits enabled by automated vehicles, such as a the ability to do something else while driving and a reduced fuel consumption lead to an increased use of the car. As there will still be mixed traffic of automated and traditional vehicles in the coming years the capacity benefits will be small.

Due an increased amount of vehicles on the road and only small capacity benefits in early forms, the amount of congestion rises. This holds especially for the autonomous scenario. In the cooperative scenario the amount of congestion will roughly stay the same. The amount of loss hours due to congestion will increase, even when they are corrected for a lower value of time for automated vehicles. Economic losses of congestion will therefore rise, while accessibility (indicated by the average speed of all modes) decreases. These effects are the largest for the highway's, on the other relations the forecasts are only mildly different.

The 'real world' environment
The lab environment shows that automated vehicles will lead to more car traffic and an equal amount or more congestion. Only in the most beneficial simulations for cooperative driving positive effects are found. In simulations which take other factors influencing mobility into account, the real world environment, it can be seen that the effects are small compared to other factors. Due to a rough estimation of external factors it is hard to make a clear forecast, however the simulations can be compared. The simulations do not show large differences between the run with automated vehicles and without automated vehicles. It can be seen that population growth or new roads have more effect on average trip speeds and on the mode choice than automated vehicles.

Effects on different road types
The effects on highways, indicated by the simulations of relation 37, show the most extreme results. Here the amount of car traffic rises strongly due to automated vehicles (9% in the cooperative lab environment), whereas on other relations this is between the 0 and 2%. The effects on the highway will be the largest as there the value of time advantages are the largest (80%). Also the fuel economy advantages are the largest here.

In inner city traffic, indicated by relation 1, the average speed roughly stays the same. However, the bandwidths are large. Here is shown that the uncertainty which automated driving enables is large and should be investigated. An effect of a 10% higher PCU value can lead to 40% extra loss hours.

Cooperative driving is most beneficial for mobility

From the two simulated development paths the cooperative path, where cars can form platoons, is the most beneficial from a mobility point of view. In this path extra capacity effects arise after 40% penetration rate. This makes that in the cooperative path average speeds of car trips roughly stay the same, whereas in the autonomous path they are excepted to drop.

Early forms of automated vehicles may lead to a decrease in mobility, but highly or fully automated vehicles (level 4 and 5) enable more benefits (Milakis et al. 2015), therefore the innovation should not be stopped or decelerated, but the expectations at this moment are too high. This research shows that new roads still need to be built investments in public transport should increase.

Besides investing in infrastructure it is can also be seen that the cooperative driving enables more benefits than autonomous. Surely with a vision to higher forms of automation, it is advised to invest in cooperative technology, or to create simulating policies for cooperative driving.

9   Conclusions and recommendations

Impacts of automated vehicles are unknown by the Dutch government. Still, they are needed as a basis for infrastructural and environmental policies. The main question of the research in part A is: *what are the expected mobility impacts of the different development paths of early forms (level 1, 2 and 3 of SAE) of automated driving in the Netherlands?*

Based upon System Dynamics (SD) a model is developed. This SD-model aims to be the simplest model by which the impacts of early forms of automated vehicles can be analysed. Both autonomous driving (cars which only 'look' at the environment) and cooperative driving (cars which beside monitor the environment also communicate with other cars and infrastructure) are simulated. In this study per level of automation the value of time, PCU and fuel economy are changed. Base year of the simulations is 2013, forecasts are made for every year until 2050. The research of Nieuwenhuijzen (2015) forms the basis for the diffusion of automated vehicles. Comparisons with other models, other tests and experiments show that the SD-model can be used to do a quick scan for policy questions around automated vehicles.

9.1.   Conclusions from the method and tests

System Dynamics is a suitable method to explore impacts of automated vehicles
System Dynamics is not often used to simulate nationwide passenger traffic (Heyma et al. 1999a; Shepherd 2014). The tests and experiments with the SD-model, made for this research, show that the model is suited to give answer to basic policy questions. Compared to other models the results are roughly the same. The strong point of the SD approach is its explorative nature. This makes that different scenarios, bandwidths and uncertainties easily can be researched. For future research of automated vehicles, or other transportation related assignments System Dynamics can be used.

The SD-model needs improvements to answer all policy questions
The tests show that the SD-model is suitable to do explorative research. However, improvements still can be made. A recalibration of the mode and time of day choice is needed. Also exogenous inputs need to be taken into account more carefully (was not the research aim) and more effects of automated vehicles have to be modelled, e.g. change in trip distribution or route choice.

9.2.   Conclusions from the simulations

Automation will lead to an increase of car traffic
From all simulations, we can conclude that early forms of automated vehicles will lead to extra car traffic. This holds for all four investigated relations. For the inner city, the rural and the provincial relation the impacts are mild, on the highway relation this is larger.

On the investigated highway relation the amount of trips in peak hours rises with 6% in the autonomous path. In the cooperative path this is 9%. In the lower bound scenario still 2% extra trips are made by car in the rush hours. In the upper bound scenario 15% extra trips are made by car. The main drivers for this rise are personal benefits as a lower value of time and fuel economy advantages. Especially the diffusion of level 3 vehicles enable such benefits. In the cooperative path the growth in car trips is higher due to advantages which arise due to platooning (capacity benefits and a higher

fuel economy). The extra car traffic leads to a decrease for all other modes. These extra trips will also lead to higher CO_2 or other emissions.

On the other three relations the speeds decrease a little. The same holds for the loss hours, which increase a little. On these inner city, rural and provincial relation the indicators point in the same direction as on the highway relation, however, with smaller figures.

Only in the most beneficial scenario the average speeds of car trips will rise
Due to extra traffic on the roads more congestion will occur. Especially in the autonomous development path, where average speeds between the four large cities during peak hours are expected to drop by 4%. The economic loss of congestion is expected to rise by 12% on highways for autonomous vehicles. On other relations smaller increases can be observed.

As cooperative vehicles will have extra capacity benefits, the congestion in the cooperative path is not expected to drop as much as in the autonomous development path. Nevertheless, the average speed drops with 1% for cooperative driving on highways. Loss hours are expected to increase with 4% (VOT corrected). Only in the most positive scenario cooperative driving will reduce congestion. More vehicles can also lead to more mobility, still in both scenarios the average speed on the relations averaged over all modes stays the same or decreases. On other relations speeds and loss hours roughly stay the same.

It should be mentioned that not all effects of automated vehicles are taken into account, but the missed effects (longer trips, spatial effects, more trucks) will probably lead to even more car traffic and congestion. Still, this does not mean that automated vehicles have no benefits, benefits in terms of spending time differently or an increase safety are not taken into account. However, the impact on mobility is slightly only positive at best, but more likely to be negative.

Difference per road type
On highways the effects of automated vehicles are the largest. On the other road types the indicators point in the same direction, however, with smaller figures. On all relations the amount of car traffic increases. Due to the extra vehicles increases especially in the autonomous path the amount of congestion.

The difference upper and lower bandwidths are the largest for inner city traffic. This relations illustrates best that a small negative effect on capacity (10% less) can have large consequences on the amount of loss hours (40% extra loss hours). This shows that already with a small share of automated vehicles can have a significant impact.

Cooperative driving is the most beneficial development path
From the simulations it can be concluded that the cooperative development path is the most beneficial in terms of congestion, loss hours and emissions. A very rough cost benefit analysis indicates that investments in cooperative driving are at least worth researching more closely. If the Dutch national government wants to invest in cooperative driving, they have to make sure that a large share of the vehicles are equipped with cooperative functions. Under 40% penetration there are no advantages, from there on the advantages will rise. Equipping non-automated vehicles with hardware enabling cooperative vehicles to follow them does not seem to be beneficial.

9.3. Recommendations to planners

The SD-model is suitable for analysis of different policies. Based upon the policies simulated in this study the following recommendations can be given to policy makers.

Early forms of automated vehicles will not solve the congestion problem
Literature indicates many positive effects of automated vehicles: safety, different use of the time and even more pronounced effects for full automation (level 4 and 5 of SAE). However, according to this reserach (level 1, 2 and 3) automated vehicles are expected to lead to extra car traffic without the desired capacity benefits. Extra car traffic can lead to extra mobility, but the average speed on the relation (average of all modes) stays the same in the cooperative scenario, and decreases in the autonomous scenario. Furthermore, will extra car traffic lead to more congestion and emissions. Only investments in new roads or more attractive alternative modes of transport can change this. Investments in infrastructure are required, and maybe even more investments than in a world without automated vehicles.

Cooperative driving leads to more mobility advantages than autonomous driving
Both autonomous and cooperative driving will lead to extra congestion. However, is it probably still worth investing in cooperative driving for the government. Main reason is that cooperative driving leads to less congestion than autonomous driving and enhances opportunities for cooperative vehicles of level 4 and 5. Still, more research is needed to see if it is worth investing in cooperative driving. The SD-model can be a tool to make a rough indication of the benefits. If the model is extended with a CO_2 module, is made suitable for all zones and recalibrated, an even better forecast can be made. At this moment it can be seen that only strongly supporting policies are worth investing in. Cooperative benefits only arise after 40% penetration rate.

A small negative effect on capacity can have a large effect on congestion
What can be seen from the simulations of different road types is that a small effect on capacity (a slightly higher PCU value) can lead to a large increase of congestion. A 10% rise in PCU can cause 40% extra loss hours, as can be concluded from the inner city simulations. Sensitivity analysis shows that for a 20% rise this is already 70%. Regulation or other measures, not only upon safety, but also on traffic flow characteristics is needed to make sure traffic efficiency is guaranteed. In the integration of both parts in chapter 15 this will be discussed in more detail.

9.4. Future work

The future work section is split up into improvements for the SD-model, improvements for other models based upon the insights of the SD-model and future research for automated vehicles.

Improvements for the SD-model

The SD-model certainly can be improved. In this section only improvements are mentioned with respect to the explorative nature of the model. Aspects which change the nature of the model, for instance the addition of an explicit network, are not discussed.

Two types of improvements are mentioned in this section. *Improvements* on concepts which are already in the model and *extensions* of the model to be able to simulate new features.

Improvements: recalibration and more accurate exogenous inputs
Almost all improvements come down to the use of data. A recalibration of the time of day and mode choice is required in future versions. The way of calibrating and the use of OViN lead to an over-sensitive mode choice and a too static time of day choice. Also the relation between the free-flow speed and the capacity should be recalibrated. Currently this is estimated based upon OViN data, but floating car data will improve the quality of the data. With floating car data, the speeds on a relation can be calculated more accurately.

Not only the calibration data, but also the input data for exogenous changes of the model is a point of improvement. Translating policy documents into inputs for the model is hard. Therefore this is roughly done in this study, because the focus was on simulating the effects of automated vehicles and not mobility changes due to other factors.

Extensions of the model
The extensions of the model are new modules or features which can be programmed in the SD-model. Some hold for simulating automated vehicles, others also for traffic in the base run. A longer explanation can be found in appendix G , but the highlights are summed up here:

More relation types
The 42 relations are characterised in 4 trip types according to their main road type. All types have specific free-flow speeds. Investigation of these relations indicate that per type the average speeds sometimes differ by as much as 20 km/h. This is too much to have one free-flow speed. In the SD-model the free-flow speeds are therefore only based on one relation, making it not applicable for roads of the same type. If the model is simulated for all relations, more trip types will have to be created.

Different travel purposes and personal characteristics
In the SD-model all trips are aggregated per zone and distinguished in two categories: car available or no car available. This is done to keep the model simple. The ScenarioExplorer works with age, demographic category and trip purpose. When for instance Ventity (new System Dynamic software, now in beta) is used, subscripts easier can be made with these variables in it. When this is done more detailed simulations and analysis can be performed.

Longer trips due to automation of the fleet
The SD-model has a static destination choice over time. Due to a lower value of time or a faster travel time the working or home location of people can differ if they buy an automated vehicle. Modelling trip distribution can harm the explorative nature. However, a way to work around this is to work with elasticities between travel time and the travelled distance. The travelled distance will rise if the value of time or travel time decreases. Problems are that these relations are not present in literature and longer trips 'consume' more capacity.

Assignment with different BPR functions

At this moment one trip, which uses multiple road types, is summarised into one speed-flow function. A better option might be to simulate a trip from Amsterdam to Den Haag with multiple BPR functions. One for inner cities, one for ring roads, one for a highway, than another ring road and inner city. The total travel times are summed up and fed back to the mode and time of day choice.

Assignment with more parameters than capacity
At this moment all effects which can cause delay in a network are summarised in the speed-flow function. However, different effects could be modelled in different functions. For highways speed-flow functions are suitable, but for traffic in cities a factor for traffic lights might be more suitable. If trips are split up in multiple blocks (as is advised in the previous point), not all these blocks have to be speed-flow curves.

A more related capacity and overlap factor
Another weakness of the assignment is the static overlap factor. In the current SD-model this factor is derived from the ScenarioExplorer. For future models it is advised to make this factor dynamic; this means that all relations have to be simulated simultaneous. If multiple BPR functions in line are used also multiple overlap factors need to be used. These factors are easier to derive as they hold for one link of a network or trip. With a selected link analysis they can be derived. This is another advantage of using multiple BPR functions in line.

CO_2 and other environmental indicators as output
With the information generated by the model a rough CO_2 calculation can be made for the Netherlands. The simplest set-up is to multiply the CO_2 per driven km per vehicle type with the amount of vehicles and the driven distance. For more elaborate modelling also congestion can be taken into account via the speed-flow curve, or even via the amount of loss hours. In the same way the effects safety can be modelled. Then an estimation has to be made how many accidents there are per level per road type.

A time dependent PCU factor
In the SD-model, the PCU for automation is dependent on the penetration rate. However, as technology gets more mature the PCU can decrease over time. If this is done, a 3D function for the PCU has to be constructed. This means that with the same penetration rate over time the PCU can also differ.

Level 4 and 5 in the model
At this moment, the SD-model is not meant to simulate level 4 and 5 automated vehicles. As this will become relevant in the coming years appendix G discusses briefly changes to the model for level 4 and 5.

Improvements for other models simulating automated vehicles
This model uses some new concepts for modelling of automated vehicles. Here some concepts that can be used in other models are summed up.

Modelling different user classes
What Snelder et al. (2015) mention as a wish for macroscopic models is realised in this model: the modelling of different used classes in the supply and demand. In the follow-up research, Snelder et

al. (2016) also elaborate on simulating multiple classes in the assignment. This way of modelling leads to a better representation of reality but also to more possibilities to simulate scenarios or policies. Especially mixed traffic in levels, or cooperative and autonomous vehicles can be modelled in this way. Besides that, the model can be explained more easily to the policymakers who interpret the results of the model. Some microscopic models and models to simulate impacts of ITS already incluide different user classes for cars.

Automation changes the flow instead of the capacity
One of the possibilities that the use of different user classes enables is that the assignment can be performed with mixed traffic. In macroscopic models the capacity is changed to simulate automation of the fleet. However, if in the assignment the flow is changed with a PCU per level, mixed traffic can be simulated more accurately. This means that not the capacity rises, but the flow drops. A normal vehicles still consumes 1 capacity unit, where an automated vehicle only consumes 0,9. This PCU can also be made variable over time or dependent upon the penetration rate. Due to this, effects of cooperative driving and autonomous driving can be simulated separately. With this modelling concept different levels of automation can macroscopically be taken into account.

Future research
Besides the aspects on which the model itself can be improved also some future research can be formulated.

Cost benefit analysis on cooperative driving
The government might be interested in investing in cooperative technology. However, they probably will need a Cost-Benefit analysis on cooperative driving before investing. The SD-model can be used as a basis for that, but additional sources are required. The amount of cooperative vehicles can be included in the model as variable based upon the investments of the government. If the SD-model is extended with an emission output and can simulate multiple relations the benefits can be calculated roughly. The costs should come from other sources.

Microsimulations or field tests to calculate the *PCU-penetration rate* relation
Predicting impacts of automated vehicles is a game full of assumptions. The change in capacity on the road (see chapter 5.4) due to automated vehicles is one of the most discussed topics in literature. At this moment the available microsimulations almost exclusively simulate straight roads without bottlenecks. A simulation study where a network is simulated with different penetration rates of automated vehicles is desired. With this information the PCU-penetration rate function can be constructed. Most desirable is if this is done for different network types (inner city, rural, highway) and done per SAE level for cooperative and autonomous driving. Macroscopic simulations can build on these insights. A step further and even better, is if these microsimulations can be validated with field tests.

Vision on modelling automated vehicles
The use of the SD-model
At this moment the SD-model is the only model, so far known, that simulates the effects of automated vehicles on a macroscopic scales as a separate mode. However, in a few years more macroscopic models will have the ability to do this, probably on a more detailed level.

At this moment the SD-model works both explorative for modelling concepts (as discussed earlier in the future work section) and explorative for policies. Both advantages can still be used if other models can simulate automated vehicles as well. The first, exploring concepts, can be used for other constructs such as modelling multiple BPR functions or a feedback loop from travel time to the amount of kilometres travelled. The second aspect, exploring mobility scenarios, will be of use to base policies upon or to give input for more detailed simulations. Another way of using it is as a tool to gain insight in the dynamics. The rough model structure is quite simple to understand and can be communicated to policy makers. Graphs as the simulation of the separate effects can be insightful for policy makers.

Other models simulating automated vehicles
To represent automated vehicles correctly automated vehicles should be modelled as a separate mode. It is important that other macroscopic models make this shift and not stay with changing the average car. This has two reasons; first that this concept represent traffic more correctly, and different mixes of traffic (autonomous and cooperative, or different levels) can be investigated. Second, it is easier to translate microscopic research to macroscopic research by doing this. Microscopic research preferably has as outcome the capacity effect for different penetration rates, which is easy to translate to macroscopic research when cars are modelled as spate mode.

When level 4 and 5 vehicles are on the road new difficulties arise. Then not the vehicles, but the passengers themselves need to be modelled too. This brings new challenges for automated vehicles. A option is to leave the current models as they are and start with a new generation models also able to simulate the rigid differences level 4 and 5 have.

Part B

Social desirability of different development paths

Short summary and reading guide

The introduction chapter (1.4) explained that the automated vehicle innovation at this moment is no responsible innovation. Five points of criticism where the innovation lacks responsibility were addressed. The goal of this research is to develop and test a constructive dialogue method to reflect with multiple actors on the automated vehicle innovation. This improves the current innovation on two of the five points of criticism : the non-inclusion of important actors and the risk of neglecting their fundamental ethical principles.

This research investigates to what extend multiple actors (consumers, non-consumers, government and car manufacturers) together can reflect on scenarios for automated driving. First, in chapter 10 is explained that the constructive dialogue should be based upon values. These values are the fundamental ethical principles of the participants. In this chapter also criteria are set which the method should meet and will be tested on. Secondly, chapter 11 presents the method developed for this research. This method consists of two steps. First via interviews and a questionnaire (n=144) a value profile per actor group is created. The second step of the method is a workshop. In this workshop the constructive dialogue takes place. Chapter 12 shows the results of both steps. In chapter 13 the results of both steps are discussed.

Chapter 14 sums up the conclusions and an outlook for future work. The tested method can be called a constructive dialogue. Furthermore it can be concluded that the method can contribute to a more responsible innovation.

10 A constructive dialogue about values

In the first chapter of the report, the problem and main questions of the research are introduced. The introduction made clear automated vehicles can have large impacts on society. At this moment the public is not or not enough involved in the development of the automated vehicles. Therefore a constructive dialogue between the government, the manufacturers, the public (both users and non-users) should be set-up. By involving all important actors, their fundamental ethical principles can be used as starting points for design. The main question of this research is: *to what extent can a constructive dialogue method be developed to give input for future designs of automated vehicles?*

This chapter first highlights that a debate with the public on automated vehicles is difficult. It is explained that there is no collective language and the members of the public all have a different view on automated vehicles. This is followed by the introduction of the concept values, which can be seen as a collective language and can be translated to design input. These two aspects and the freedom of a designer, meet each other in the method of *Value Sensitive Design*. This method is explained in the third part of the chapter. This chapter finishes with criteria that the method should meet to be called a constructive dialogue method.

10.1. Responsible innovation: focussing on a dialogue

As explained in the introduction (section 1.4) the automated vehicle innovation can't be called a responsible innovation. This research focusses on two of the five mentioned points of criticism : the non-inclusion of important stakeholders and thereby the possibility of neglecting fundamental ethical principles of these stakeholders. Both points overlap, as due to the inclusion of stakeholders they can express their ethical principles. Next step is that a manufacturer or a government takes the principles into account in policies or the final design. This last step is important, but out of scope of this research.

Complicating factors for reflection

If would be great if all actors immediately could start with a constructive dialogue, but there are two aspects missing in this dialogue. These are that 1) there is no collective image of the future automated vehicle and 2) that there is no collective language that the actors speak. Next to these missing aspects should the freedom of the designers be guaranteed. All three are explained in this section.

What the future automated vehicle will look like is still uncertain
How level 1 and 2 automation will look is clear as the vehicles can be bought in stores. However, the fog around level 3 and higher levels of automation has not lifted yet. Due to different technical scenarios, different business models and different policies the final form of an automated vehicle that will be on the road is still unclear. Caused by these uncertainties the car can be developed in multiple ways.

As a result of all these factors the problem arises that there is no "kollektive Vorstellungsbasis" around the automated vehicle (Fraedrich & Lenz 2014, p.47). This means that the public has no *collective view* on the automated vehicle. Therefore, if people are asked on what they think of an

automated vehicle, they all picture something else in their heads. Not only the public copes with this problem, also governments had this problem and asked for scenario studies like "Chauffeur aan het stuur?" of the KiM (2015) or scenario workshops of the TU Delft for the planning bureau PBL (Milakis 2015). In these studies different scenarios are explained to give more structure to the innovations.

Due to the different views of people on the vehicle surveys to automated vehicles are questionable. Many surveys ask questions like: '*do you like automated vehicles?*' or '*would you buy an automated vehicle?*' (Kyriakidis et al. 2015; Casley et al. 2013; To Connect 2015; Schoettle & Sivak 2014). Most of them do explain what type of automated vehicle they mean, but still many aspects remain unclear (the effect on traffic flow, business model, privacy issues). What is mostly done is asking people to reflect on something that is not clear. In this way an downstream method is used in a phase where an upstream method is needed (Schuurbiers & Fisher 2009).

It is preferred not to ask '*what do you think of an automated vehicle*', but to formulate it more utopian: '*what would an ideal automated vehicle look like?*' In this way the differences in image become clear and all concerns and expected positive points can be used as input for design. The research of Fraedrich & Lenz (2014) does this. They extract opinions from comments under news articles on websites.

Experts and non-experts speak another language
Another complicating factor for a dialogue between manufacturers, researchers or government officials with the public is the lack of a common language (Kerr et al. 2007). Where experts mainly reason from *ratio*, the public often reasons from *emotion* (Roeser 2012). Examples of complicated debates are genetically modified food, CO_2 storage under the ground or nuclear energy. Discussions often end with discontent from both sides: the public blames the expert for not listing and the expert grumbles the public does not understand the technology.

"If I had asked people what they wanted, they would have said: faster horses"
Tricky aspect of a dialogue is that experts feel that they have more knowledge and therefore more to say in the innovation. For some of them involving the public does not make sense. Fords famous quote: "If I had asked people what they wanted, they would have said: faster horses" summarises that view. Experts often think the public is conservative. Still, this does not mean that they cannot bring valuable input to the design process (von Schomberg 2013; van de Poel 1999). Outsiders in technology can bring new insights, can directly state their interests and can increase the support for an innovation. These are the instrumental arguments Fiorino (1989) names (see chapter 1.4). Van de Poel (1999, p.1) explains that "outsiders may be an interesting entry to recognize and exploit the potential for more 'societally desirable' forms of technical development that, for example, take away undesired effects of existing technologies".

Still, the role of the expert should be valued. Important for designers is that they still need freedom to design. The knowledge, creativity and capacity to link different subjects of the expert should be used. However, experts can work with input of outsiders. The quote of Ford is often used as an argument to eliminate all input from the public. It is preferred to change the quote of Ford to "If I had asked people *directly* what they wanted, they would have said: faster horses". Than indeed the role of the expert is not valued. Asking input at the start (upstream) is preferable. This leaves the

option open to research indirectly what people want. If Ford had asked how people ideally would be transported they probably would have answered 'with a higher speed and some shelter for the rain'. This means that input can be given 'upstream' (Sutcliffe 2011, p.13).

figure 10-1: Doom scenario of a techno-push of automated vehicles. Drawing by Ayelt van Veen.

10.2. Values as a basis for a dialogue

From section 10.1 it can be concluded that a common language is needed to give input to designers. A method that meets these requirements is a dialogue based on *values*. What values are and how this dialogue should look like is discussed in the following paragraphs.

Values are the basis of the choices of people and institutions
The concept of a *value* is often used in its economic sense: 'this car has a value of 5000 euro'. However, in this work, the value is seen in the intrinsic way. Examples of these kind of values are privacy, speaking the truth or friendship.

Values form the guidance for behaviour and make it possible for people to make choices (Rokeach 1973). Values where already of interest since in the time of Plato (Frankena 1972), are culture dependent (Hofstede 1992), change per context (Witesman & Walters 2014) and are learned in the early childhood (Hofstede 1992; Rokeach 1973). Values are more or less stable for a person and only change little over time (Abramson & Inglehar 1995).

Values are not only human, also institutions set their values. Ever since the ancient Greek society values have been named and used to base governmental decisions on (Witesman & Walters 2014). Also companies or NGO's state their values in their mission statements or visions.

Definition of value

Values are defined in many ways. The clearest definition found in literature is the one of Oppenhuizen & Sikkel (2000). They use a short form of the definition by Rokeach (1973) which is often used in literature. The definition reads as follows, "*a value is a state or behavioural manner which people find worth striving for*." The definition is extended with the fact that governments, companies and other institutions that define their values in mission statements or political visions. Therefore, our own definition is created. The used definition value in this thesis is:

Definition: A value is a state or behavioural manner people or institutions find worth striving for

10.3. Using values in design

Technical designs embody values (Winner 1980; van de Poel & Kroes 2014; Flanagan et al. 2008) . Therefore a designer should always be aware of the fact that his or her design strengthens or maybe even violates certain values (Roeser 2012). An example in the transport domain is intelligent speed assist (ISA), which sets a maximum to the speed. This strengthens the value of safety, but has a negative effect on the autonomy of the driver.

From value to boundary conditions

Technical products have functional boundary conditions, but can also have moral boundary conditions (Van den Hoven et al. 2012; Flanagan et al. 2008). These moral boundary conditions is what this research is investigating. Values of the different actors are the input for those moral boundary conditions. The relation between moral values and design is described by Van de Poel (2013) in his paper: *Translating values into design requirements.* He explains values can be specified to norms ("Rules that prescribe what actions are required, permitted or forbidden"(van de Poel & Royakkers 2011, p.175)). These norms can be specified to design requirements. For example: the value 'sustainability' can be specified to the norm 'less fuel consumption' and the design requirement 'an engine of type Z'.

Literature also describes several levels of values. Sustainability can be seen as value on its own, but sustainability can be seen as a form of caring for next generations. There are several attempts done to find these 'global', 'terminal' or 'basic values' (Zimmerman 2004). Rokeach (1973) for instance defined 18 'terminal' values, for instance love, friendship or wisdom. These values are too vague for this research and people find it very hard to answer questions at this level (Oppenhuisen & Sikkel 2000). In figure 10-2 is shown how values, norms and requirements fit together. Van de Poel (2013) calls this a 'value hierarchy'. From top to bottom values can be "specified", from bottom to top there are "for the sake of" relations, as Van de Poel calls them. In this research the context specific values are researched.

This research searches context specific values and aims to specify these to norms
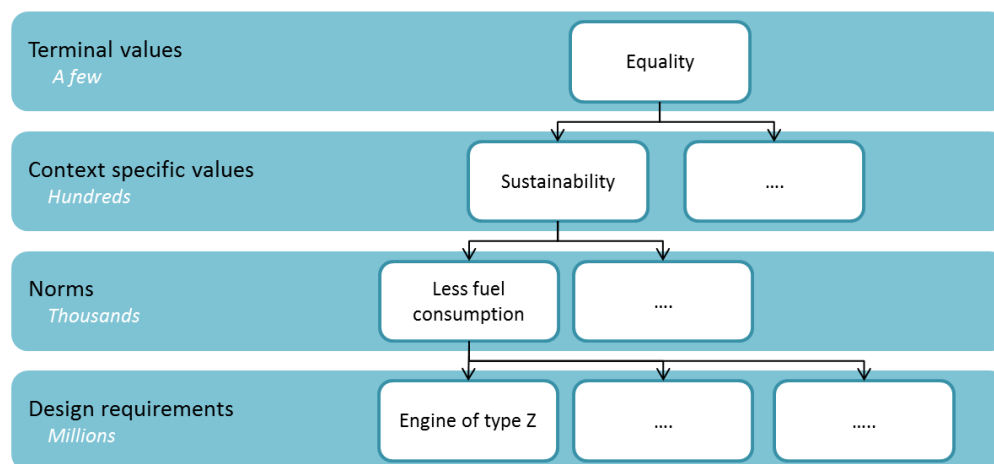
figure 10-2: In this research the context specific values are researched, which are used to formulate norms for future automated vehicles. The figure is based upon Rokeach (1973), Oppenhuisen & Sikkel (2000) and Van de Poel (2013).

Linking actors to the steps of the value hierarchy

Investigating the context specific values has to be done with a high diversity of actors (Cuppen 2012, p.1), as these values are set by all actors. The next step, the specification of values to norms has to be done with a combination of experts and non-experts (van de Poel 2013, p.261). This is needed as both domain specific knowledge (information about automated vehicles) is required, and context specific knowledge (what an actor wants). In this way *'morality will be materialised'* (Verbeek 2006, p.2), not only by engineers, but by the all relevant actors.

In order to guarantee freedom for designers the specification from norms to design requirements has to be done by experts. Van de Poel (2013) also advises this. There are other methods in the design step (midstream modulation or more downstream methods) to keep eye on values of the actors involved. The intended values of a design do not have to be the realised values. These methods are outside the scope of the research.

Who to involve in the dialogue

In the introduction (section 1.4) is explained that there are four important actor groups which need to be involved: the manufacturers, the government, the user and the non-user. These groups are still defined broadly. As in the proposed dialogue values need to be discussed, the involved participants should have a connection with the values (Oppenhuisen & Sikkel 2000).

For the public (the non-user and consumer) there will be a diversity in the values, as there are many diverse people. For these groups it is of importance that many and a diverse group are investigated (Cuppen 2012, p.1). Representatives of the public, such as the government or interest groups, can be involved, but represent and are not the source of the values. Still, the ANWB (interest group for road users) can be asked for input of values, but won't take place in the dialogue.

For the manufactures holds that we are searching for the values of the organisation. As automated vehicles are rather novel and there is uncertainty, websites or press releases do not cover all values. Therefore we will use other empirical investigations. As in car manufactures not everyone is working

with self-driving cars, we need to involve people working with automated vehicles. Preferable managers or other employees with a more strategic vision. If that is not possible multiple people should be investigated. With car manufacturers we should keep in mind that they are not one group, but are different companies. A diversity of companies should be investigated.

For the last group, the government, holds that the investigated persons also should work with automated vehicles. They are able to translate governmental principles to values related to automated vehicles. The government of course has multiple levels, but as already is explained in the introduction, we focus on the national government as they are now mostly working on automated vehicles. In the 'working group self-driving cars' different institutions of the government work together to start initiatives and work on policies. Members of this group are therefore good representatives of the government.

This method in relation to Value Sensitive Design
Using values as input for design is not new. Both Value Sensitive Design (Friedman & Kahn 2002) and Values at Play (Flanagan et al. 2008) argue for a design based upon values. However, in most cases, one actor or one actor group is used to give input to the designs This is often the user of the technology. As in the automated vehicle innovation multiple actors are influenced they should be involved in the performed study. Therefore all values are used as input for the design.

Most Value Sensitive Design studies are done within the software domain (for example Meijdam 2015; Friedman et al. 2002 or examples in Flanagan et al. 2008 and Friedman & Kahn 2002). With this research to automated vehicles, the context differs. Still, automated vehicles can be seen as an innovation where software and cars meet. Therefore, this research is a small step outside of the current research area. This is interesting as new values will be at play. Where traditionally privacy is important in software (see for instance Privacy by Design), in this study safety and traffic flow will be more of interest. Also new is that the innovation affects the non-user.

10.4. Criteria for a constructive dialogue for automated vehicles

The first sub-question of the research is: *which criteria should the method meet to be a constructive dialogue?* The term *constructive dialogue* is used a few times in literature (Litz 2008; Jokinen 1995; Nanopodium 2015), but never defined. Therefore, our own definition is created, together with some criteria when a method can be called a constructive dialogue.

In this chapter several aspects are mentioned which set criteria for the method. These can be categorised in three parts. Later we will zoom in on each of the parts. First, the method should be constructive. Secondly, the method should be a dialogue. Third, the method should meet the innovation specific boundary conditions. At the end of the section table 10-2 summarises all criteria.

The method should be constructive
The 'constructive' element in the method originates from the Constructive Technology Assessment (CTA). Traditionally Technology Assessments (TA) investigate the possible consequences new technologies have (Schot & Rip 1997). This is often done by experts, sometimes in cooperation with the public. A variation of TA is the Constructive Technology Assessment (CTA). This CTA is developed

in the Netherlands. CTA has not only the goal to assess, but also to influence the final design. Often with together with the public. Schot and Rip (1997, p.154) call tis "aimed at influencing technological choice and design processes". This is similar what Stilgoe et al. (2013) or von Schombergen (2013) have in mind with Responsible Research and Innovation. Especially the reflexivity element of Stilgoe et al. links with the definition of the 'constructive' element.

The method should be a dialogue
A dialogue can be defined simple, as communication between two or more parties. However, also requirements which a dialogue should meet can be set. Smaling (2008) explains in his work that a dialogue should meet 5 criteria: equality, mutual trust and respect, openness, argumentative quality and a reflective nature. In his work he also defines a critical dialogue, which should focus on reflection and cooperation of the participants. For this thesis the method will be tested to the criteria of the dialogue, for further research a critical dialogue might also be of interest.

Smalling (2008) has made definitions for these 5 criteria. They are shown in table 10-1 (the defintions from Verhoeffen & Kupper 2014, p.9 are translated from Dutch).

table 10-1: overview of all aspects which make a dialogue a dialogue according to Smalling (2008). Definitions from Verhoeffen & Kupper (2014). The words in *italics* are specific aspects which need to be checked upon in the method.

Equality	*Every participant* should be able to *set the topic*, *ask questions* or *have a discussion.*
Mutual trust and respect	From the behaviour and language it can be concluded that they *respect each other*, *also in being different*. They also believe that the other *party is honest*.
Openness	All parties *share relevant knowledge* and emotions and try to interpret each other as good as possible. They *help each other in formulating arguments*.
Argumentative quality	Statements from the participants are *based upon acceptable arguments*. Discussion tricks or fallacies are not used.
Reflective nature	The participants think about their role and see the dialogue as the four aforementioned aspects.

Besides these positive criteria it is also good to analyze the dialogue on the opposite of the criteria. This will be explained later on in chapter 11.1.

Davies et al. (2009, p.338) distinguish two types of dialogues: "policy informing dialogue events" and "dialogue events that do not seek to inform public policy". The type of dialogue needed here is a policy informing dialogue. These kind of dialogues have much more success if they are embedded in formal policy making (Joss 1998). Embedding the dialogue in a formal decisions making is of importance for policy making around automated vehicles, but out of scope of this thesis. The discussion (chapter 13) will highlight some options for using the method in practice.

Other criteria the method should meet
The automated vehicle innovation to cope with complex situations. These aspects here are a summary of the aforementioned aspects in this chapter. First of all, there are multiple actors in the innovation important stakeholders. Difference in the automated vehicle innovation is that the government has a strong regulating role. Besides that has the innovation effect on non-users of the

technology. Ipads for instance, barely have an effect on outsiders of the users and are not regulated that much as automated vehicles. So, the method should include two expert groups (government and car manufacturers), and two groups of lay-people (consumers and non-consumers). Second point, which holds for more innovations, is that the designers need freedom (example of Ford's quote). Thirdly, the method should overcome two problems: there is no clear image of self-driving cars at the public (Fraedrich & Lenz 2014) and their effects are still uncertain (Fagnant & Kockelman 2015). On all criteria the developed method should meet.

Criteria for the constructive dialogue method
The criteria per aspect are summarised in table 10-2. The used method should be tested on these criteria. Some criteria should be tested in the method itself (for instance *equality* or *openness*), whereas others are inherently connected to a certain method, such as *freedom for designers*.

table 10-2: Overview of the three types of criteria the constructive dialogue method should meet.

Aspect	Criteria
Constructive	Aimed at influencing technological choice and design processes
Dialogue	1. Equality 2. Mutual trust and respect 3. Openness 4. Argumentative quality 5. Reflective nature
Innovation specific	1. Multiple actors 2. Freedom for designers 3. Overcome that there is no clear image of the self-driving cars 4. Overcome that there is no common language experts and public

10.5. Structure of the report

The previous sections describe the approach that will be used in this research. The context of the research is Responsible Research and Innovation (RRI). Comparing the automated vehicle innovation to these the criteria from RRI five striking points are raised. From these 5 points this thesis focusses on the two most important: the non-inclusion of important stakeholders (the public) and therefore the possibility to neglect their ethical principles.

This research includes these stakeholders and aims to develop a dialogue about values. These values are the aforementioned fundamental ethical principles. An approach linking values to design of technical artefacts is Value Sensitive Design. This branch of research argues for doing multiple types of investigations, in this research is focussed on the 'empirical investigations' (Friedman et al. 2013). The traditional Value Sensitive Design approach will be enhanced with insights from other methods.

Problem originates from

Responsible Research and innovation

Zoomed in on 2 aspects:
- *Neglectance of ethical principles*
- *Non-incluision of important stakeholders*

Method originates from

Value Sensitive Design

Empirical investigations
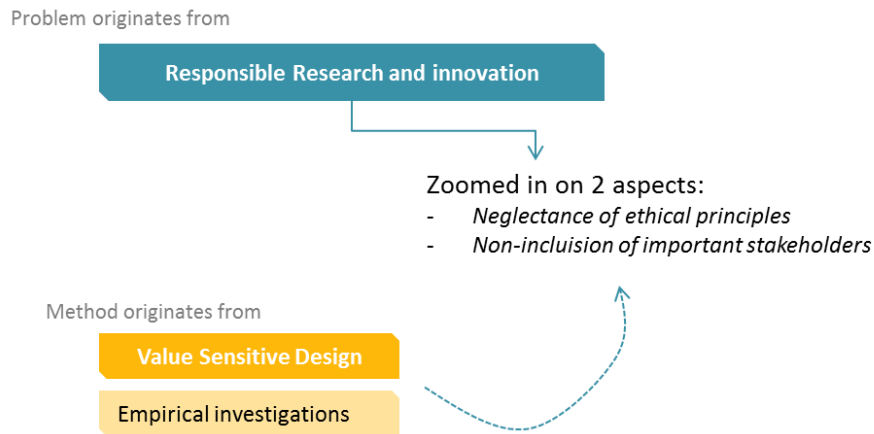
figure 10-3: The analysis of the problem is done from a Responsible Research and Innovation perspective. The method originates from Value Sensitive Design and mainly its empirical investigations. This is enriched with other methods (see chapter 11)

The sub-questions this research aims to answer are:
1. Which criteria from literature should the method meet to be a constructive dialogue method?
2. What values, of the relevant actors, are at play in the development of automated vehicles?
3. What is the relative importance of the identified values per actor?
4. To what extent can one common value profile be created in a constructive dialogue?
5. Which value tensions become clear when the values are specified to design input?

The results of the first sub-question are already shown in section 10.4. The results related to the second question will be shown in the first part of the results, just as the third sub-question. The results of the fourth question will be addressed in the second part of the results, just as the fifth. These sub-question answer the main question of the research: *to what extent can a constructive dialogue method be developed to give input for future designs of automated vehicles?*

What to expect in the rest of the thesis
In this chapter the literature on which the method is based is explained. The next chapter (11) discusses the method in detail. The results of all investigations are shown in chapter 12. Chapter 13 discusses the method and the results. Conclusions are drawn in chapter 14.

Overview of the coming chapters

Basis of the method

Explanation of the method

Results

Discussion

Conclusion

10

11

12

13

14
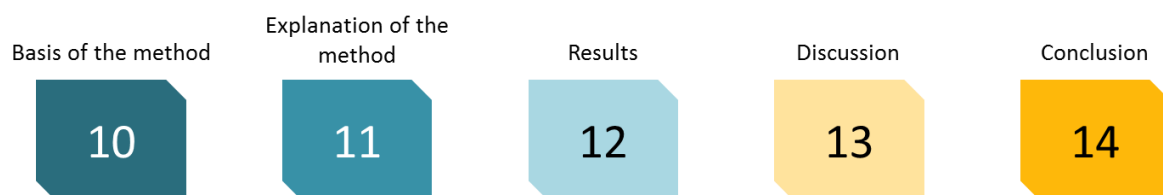
figure 10-4: Reading guide of the next chapters of part B.

11 Method for a constructive dialogue

This chapter explains the performed method. The goal of this chapter is to explain the constructive dialogue approach that is meant to reflect upon the two development paths for automated driving. The two development paths are: autonomous driving, where the car only 'looks' to the driving environment, and the cooperative driving where the vehicle also communicates with other vehicles or infrastructure. This constructive dialogue method consists of two sequential steps, schematically they are shown in figure 11-1. The next chapter contains the results of all the steps explained here.

The steps of the method
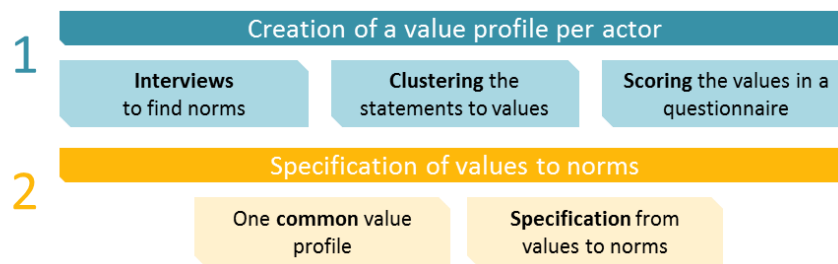
figure 11-1: The method starts with creating a value profile for each of the four actors. This is done by extracting different value from interviews and let the actors score them in a questionnaire. In the next step a workshop is organised where one common value profile has to be created and the values need to be specified to norms.

Short overview of the method

In the first step it is investigated what all actors find important. This is comparable to what in Value Sensitive Design (VSD) and Values at Play (VAP) is called the 'empirical investigation' (Friedman et al. 2013; Flanagan et al. 2008). By interviewing the actors and clustering the values an ECHO-framework created (Michalopoulos et al. 2013). The ECHO-framework is a framework where values are quantified and relative importance of these values becomes clear. After the interviews are done and the clusters are made the third sub-question can be answered: *what values, of the relevant actors, are at play in the development of automated vehicles?*

The next step is that via a questionnaire different people per actor group are asked to score the values. These are the actors named in the introduction. This step answers the second sub-question: *what is the relative importance of these values per actor?* In traditional VSD studies this is not common to do. Still, this is done to make clear where the differences in opinions are between the actors. Thus, in this first phase of the method the actors form a utopian vision on automated vehicles on their own.

In the second part the actors together try to form a common utopian vision in a workshop. This step answers the fifth research question *to what extent can one common value profile be created in a constructive dialogue?* In the second part the actors specify the values to norms (van de Poel 2013). This is the step where the constructive dialogue takes place. This answers the sixth sub-question: *Which value tensions become clear when the values are specified to design input?*

After these two steps are performed, will be tested if this method meets the requirements for a constructive dialogue. This is done with the criteria set in 10.4 (the first sub-question). This answers

the main question: *to what extent can a constructive dialogue method be developed to give input for future designs of automated vehicles?*

table 11-1: Overview of the goals, the literature and the sub-question answered per step.

Step	Goal	Based upon	Question
1. Value profile per actor	Investigating what a single actor finds important. Finding conflicts between values of actors		
Interviews	To create a longlist of moral boundary conditions of different actors.	(Oppenhuisen & Sikkel 2000; Osterwalder et al. 2014; Friedman et al. 2013)	2
Clustering	Clustering the statements to values	(van de Poel 2013)	2
Scoring	Insight in the relative importance of the values per actor	(Michalopoulos et al. 2013)	3
2. Specification from values to norms	Having a constructive dialogue by specifying the values to norms		
Scoring together	Warming-up and creating a common value profile (if possible)		4
Specification	Specifying the 8 values to norms in a constructive dialogue	(van de Poel 2013)	5

11.1. Step 1: finding the value profiles per actor
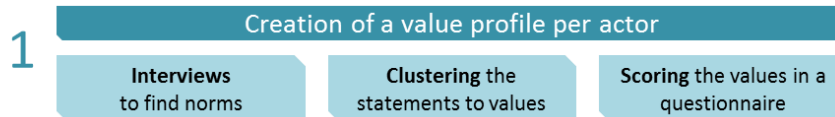
figure 11-2: Step one of the method.

Short overview of step 1

In the first step the actors (government, car manufactures, consumer, other road users) are individually researched. The goal of this step is to find the value profile per actor group. This is done based on the ECHO-framework. Michalopoulos et al. (2013, p.1) call this method "a public multi-criteria assessment for societal concerns and gradual labelling". In the first steps (interview and clustering) the criteria are determined, in the following step (the scoring) the weights of the several aspects are set by the actors. The method of Michalopoulos et al. can be used for products which are not yet existed such as self-driving vehicles, or non-existing tomatoes spiecies in their case.

Michalopoulos et al. brainstormed with experts to set with values. In this research the actors are interviewed to find their values. Interviewing is common in other literature to find values (Van de Poel 2015; Oppenhuisen & Sikkel 2000; Meijdam 2015). The scoring in the questionnaire is done by a constant sum question[36] (Survey Analysis 2015). This element is novel for Value Sensitive Design research.

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[36] A constant sum question means that a certain amount of points should be divided over several aspects.

Interviews with the actors to find norms and values

The goal of the interviews is to make a longlist of all possible values people have related to automated vehicles. As in later steps the actors need to score the same list and negotiate the same values, the outcomes are combined to one list. The representatives of the four actors, and the ANWB are interviewed in a half interview – half creative setting. The interviews are transcribed and open coded.

figure 11-3: The four actors and the ANWB are interviewed. In the interviews questions are asked about what they are enthusiastic about and what they fear of automated vehicles (AVs). Next they are asked to design a flyer of their ideal automated vehicle.
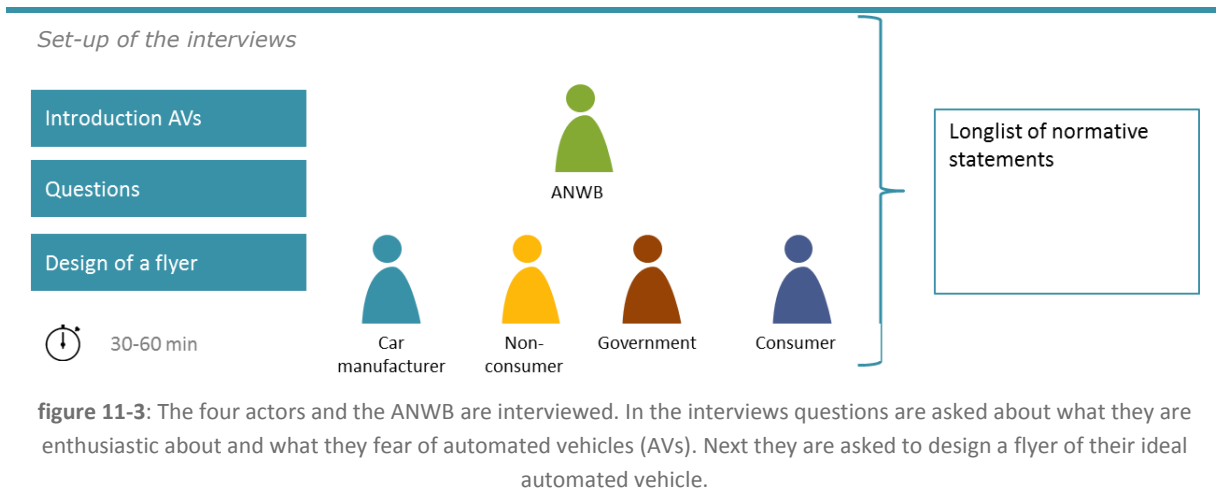
There are two ways to empirically research values: revealed preference or stated preference (Coolen & Hoekstra 2001). Revealed preference means that actions of an observant needs to be researched. As this is hard for new technology, current technologies can be researched. This is called the technical investigation in VSD (Friedman & Kahn 2002). As in automated vehicles many technologies together form a new technology (automation, cars, ICT, image recognition, radar, data processing) comparing is time consuming and complicated. Therefore the empirical investigation approach from VSD is chosen (Friedman & Kahn 2002). Empirical investigations are what Coolen and Hoekstra (2001) describe as stated preference method. This means participants have to express their values themselves.

Creative element in the interview
Downside of stated preference is that values are often hard to grasp for participants (Oppenhuisen & Sikkel 2000). Therefore, Osterwalder (2014) argues in his book Value Proposition Design for a method where customers design their ideal product box of a new product. The designs and their explanations are analysed on values. During the drawing participants are asked why they made certain choices. We make use of the same approach. This creative step is different from what is normally done in VSD research. Often 'laddering' (Oppenhuisen & Sikkel 2000; Friedman et al. 2013) is used. This means that an interviewee is asked what he finds important, followed by constantly asking "why?" As this can be found intrusive or seem childish, the creative part of Osterwalder (2014) is involved. With the designed flyer for future automated vehicles in hand values are observed and less "why" questions are needed.

As starting directly with designing the brochure is a hard task for participants (Tassoul 2009), the interview starts with questions about what the interviewees think of self-driving cars. To help the participants in the creative part, they get an A3. On the A3 is printed "The self-driving car". On an A4

some starting points are given. This A4 contains some pictures of cars (test persons started by drawing cars, which was not needed) and some starting sentences like, "We promise", "This vehicle can", "Especially for you" or "This car is not". With scissors and glue they can start designing. This should be an easier starting point for the creative part.

Set-up of the interview
The total interview is built up as a semi-structured interview, which is advised by Friedman et al. (2013, p.78). The interviewer starts by asking what the participant is enthusiastic about of the self-driving car and scared of. Next, information of level 3 automated vehicle is given. After this, the participants are asked to design a small brochure of their ideal automated vehicle of level 3. A brochure is chosen since cars do not have product boxes (which Osterwalder uses). During the drawing, the participant explains his flyer and the researcher asks some questions about the flyer. The participants get no information about the development paths, so they do not get biased.

The interviews are tested three times on students. Once only with questions, once only with the creative part and once with a mix. The mix gave the best results. In total 6 interviews are done. One with each of the actors (the government, the manufacturers, the consumers and the non-consumer). One extra interview is done with two members of the ITS[37] team of the ANWB, as they are an important lobby organisation for the car driver (so both consumer and non-consumer) and have more knowledge on self-driving cars than the public has. To check if all values are found a sixth interview is done, in the next section this interview is explained. This interview has the same structure as the other five.

The outcomes of the interviews will be a mix of values, norms and other statements (see figure 10-2 for the value hierarchy of van de Poel (2013)). In the clustering the longlist will be translated to a set of values.

Roles in the interview (consumer or other road user)
In the research the roles of the consumer of an automated vehicle and other road user are difficult. They are now all non-consumers, since there are no automated vehicles commercially available. Their roles are made explicit at the start of the interview and gain when they start designing the flyer. Also in the interview with the government and the manufacturers the roles are made clear, since they needed to answer for their organisation standpoint and not from their personal opinions.

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[37] ITS means Intelligent Transportation Systems. It is an umbrella term for all services or applications that use information technology or communication to make transportation 'smarter', better informed, safer, more sustainable. Automated vehicles are an extensive form of ITS.

Setting of the interview
The interview are taped with a telephone and take place in a private place. In the interviews first an explanation is given on self-driving cars, secondly the questions are asked, finally the flyers are designed. The total set-up of the questions of interviews can be found in Appendix H. The interviews are analysed and coded. Also a first investigation to value tensions is done. The transcripts of the interviews can be found in Appendix I. The scans the drawings from the creative step are shown in appendix J. The results of the interviews, the longlist of values can be found in chapter 12.

From interviews to clusters

The goal of the clustering is to create value clusters, which can be scored. This is created from the longlist of statements from the interviews. First the interviews are open coded and afterwards 3 experts and the researcher clustered the codes.

Clustering the statements (codes from the interviews) to values

Longlist of values

Value clusters

Literature

Experts & researcher
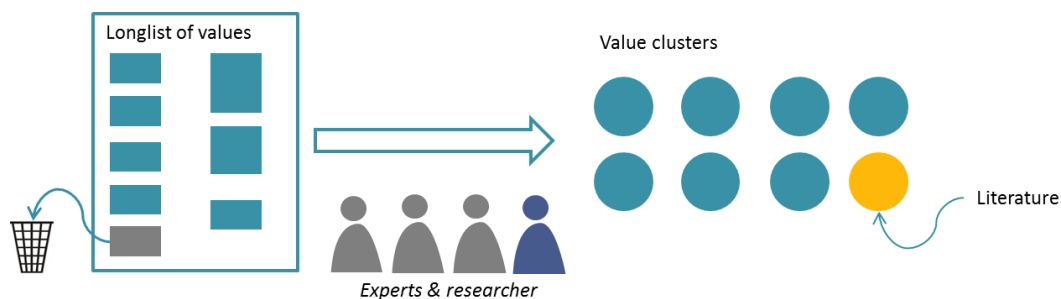
figure 11-4: The statements are clustered to 7 values. One other originates from literature. Statements which are on the process or not specific enough are left out of the clustering.

The clusters which are made need to be as MECE as possible. MECE stands for Mutually Exclusive, Collectively Exhaustive (Rasiel 1999). Mutually Exclusive (ME) means that there is no overlap between the clusters. Collectively Exhaustive (CE) means that the clusters include all relevant statements and opinions on automated vehicles. The ME is done in the clustering session, the CE is done with a check with literature and an extra interview.

From codes of the interviews to clusters
To make the clusters, first, the interviews are recorded, if the interviewee does not object. Afterwards they were transcribed and coded. The coding technique that is used is called 'open coding' (Bryman 2012, p.569) "[T]his process of coding yields concepts, which are later to be grouped and turned into categories". This type of coding is used if there is no theory available (Corbin & Strauss 1990), which is the case for values on automated vehicles.

From the codes, the researcher and three experts create a values hierarchy. The experts are two mobility experts from TNO and one researcher from the TU Delft Science Communication department. As there are multiple answers possible, the views of different people are combined in the cluster session. The experts together have knowledge about values and automated vehicles. The clustering step is precarious as it uses the codes, but also common knowledge to fill the gaps in the hierarchy (van de Poel 2013). The common knowledge is needed as sometimes the overlapping

concepts are named in the interviews, sometimes the values and sometimes statements that are none of both.

As the clusters use common knowledge the clusters are debatable, but also "more systematic, […] explicit, debatable and transparent" (van de Poel 2013, p.265). This makes the clustering hard to reproduce and not irrefutable. To gain insight in the cluster session all statements are sorted per clusters and shown in appendix K.

The names of the clusters should be a value, therefore one should be able to have an opinion on the cluster. A cluster should be found 'worth striving for' as the definition explains. Easier is to see if a cluster can be found 'important', 'not important' or 'more important than cluster X'. Clusters like 'other', 'norms starting with the letter t' or 'important for the government' are cluster names which cannot be strived for and therefore should not belong in the final clustering. These types of cluster names are rejected during the cluster session.

Making the clusters collectively exhaustive
The clusters should overarch all aspects of automated vehicle as good as possible. To make the clusters collectively exhaustive two checks are done. The first one is a literature review on values to check if all values fit in the clusters that are made. The second test is to do another interview, open code this interview and see if all the statements fit in the clusters.

After these two checks, the clusters are given definitions by the researcher based upon the outcomes of the clustering. The experts checked the definitions, after this, we tested them in a few test questionnaires.

With these clusters, the most important values of the automated vehicle innovation are defined. This answers the third sub-question: *what values, of the relevant actors, are at play in the development of automated vehicles?* The result of this clustering step are 8 values. More on the results can be found in 11.1.

Scoring of the values via a questionnaire
The goal of this step is to create an order in the values. The 4 actor groups are asked to fill in a questionnaire in which is asked to distribute 80 points over the 8 values. This gives an insight in what the different actors find important, and on which aspects they disagree. The output of this step is a value profile per actor group.

Three steps of the online survey

| Introduction into self-driving vehicles and the survey | | |

How does the survey work — *Distribute 80 points* — *Indicate why this distribution is chosen*

figure 11-5: The survey is introduced by a movie. Next the respondent is asked to divide 80 points over the values. Finally the respondent is asked why they made this distribution. The offline questionnaire only consists of step 2.

The four groups are asked to distribute 80 points over the 8 values

In interviews, but also in literature, many aspects of automated vehicles are named as being important. This research investigates the order of the values and if this differs per actor. To do so, the values are scored. With this information, a ranking of different values can be made per actor: their value profile.

Literature explains two methods to create an order in values: ranking and rating (Maio et al. 1996). For small sets of values the rating (giving points) is preferred (Alwin & Krosnick 1985). As the clustered set contains 8 values rating seems to be suitable. This is the same approach as the ECHO-framework (Michalopoulos et al. 2013). The participants are asked to distribute 80 points over 8 values. This type of question is called a constant sum problem (CSP) (Survey Analysis 2015). With the constant sum problem a dilemma is created: giving points to an aspect will automatically lead to less points at another. This dilemma is needed as in interviews people indicate they find all values important.

Set-up of the online questionnaire

The online survey consists of five pages. These are a landing page, an explanation page with video, a constant sum question, the question why the two highest scored values are score highest and the same for the two lowest values and finally a closing page. The total questionnaire is shown in appendix L, here below the questionnaire is summarised in a scheme.

Introduction in automated vehicles	On this page the set-up of the questionnaire is explained, the age of the participant is asked and the role of the respondent is explained (consumer, other road user, government or manufacturer). On the next page an explanation self-driving cars is given in two forms, by a movie [38] or in text. Again the role of the respondent is highlighted in a pop-up.
Constant sum problem (quantitative)	In a matrix of 9 squares (3 x 3) the 8 values are shown. The middle square shows the amount of points left to divide over the values. Per value a number of points can be filled in. The middle cell turns red if too many points are divided. Per value a short explanation is given. If the respondent needs more information the 'info' button shows a pop-up with a longer explanation. The pop-up also explains what will happen when many or few points are given.
Why these value scores (qualitative)	To see the motivations of people and to check if the survey is understood correctly another question is added. The respondents are asked to underpin why they have chosen the two highest scored values and the two lowest scored values. The four questions on this page are not mandatory, to decrease the dropout during the questionnaire.
Closing remarks	At the end of the survey is asked if the respondent wants to participate in follow-up research and if they have any comments left.

Offline questionnaire

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[38] An example of the movie can be seen here: https://www.youtube.com/watch?v=xnTHUstmvs4
The script can be read in appendix M .

Besides the online version, also an offline version is made. In this version the researcher gives the introduction and the scoring step is done on a scoreboard with poker chips. This offline version is suitable for places where many potential participants come together. In appendix L a picture of the offline scoring board is shown. After the participants have divided the poker chips a picture is taken. Later are the outcomes registered the same way the online surveys are registered. In the offline version no qualitative data is collected.

Roles in the interviews
For all surveys, both online and offline, the roles are made clear. The non-consumers are told they should picture themselves as another road user driving, cycling or walking next in traffic where also automated vehicles are. Consumers are told to picture themselves as a driver of an automated vehicle. To make sure everyone would fill in the correct survey four different separate questionnaires on four different webpages are created. In e-mails to the respondents only their group questionnaire is shown. In this way consumers cannot fill in questionnaires for the government (or vice-versa). For the *consumer* and *other road user* half of the people are e-mailed with one survey, the other half with the other. In the survey five times is made clear what the role is: in the e-mail, at the landing page, in the movie, in a pop-up and below the constant sum problem. The questionnaire is translated to English as the Dutch of Swedish, Japanese, American and German manufacturers is not fluent. The movie is not translated as that took too much time, only a short text is given with explanation. The text is also shown in appendix M . As these respondents all work on automated vehicles the explanation about self-driving cars is shortened.

The consumer and non-consumer questionnaires are distributed via e-mail to friends and family, and via Facebook. The questionnaires of the car manufacturers and government are targeted to people working in the departments of automated vehicles. In section 10.3 is explained which people are of interest.

In total the questionnaire has 144 responses. The response-rate is hard to determine as e-mails are forwarded and Facebook is used. More descriptive statistics on the questionnaire are presented in the results.

Analysis of the data
The outcomes of the datasets are analysed on 3 aspects: 1) the value profile per actor group, 2) the differences per value between the groups and 3) the differences in the group. Besides the quantitative analysis, also a qualitative analysis is done on the data. The underpinnings of the respondents are checked to see if they understood the questionnaire. The quantitative analysis are summed up here below.

Value profile per actor
The value profile per actor seems easy to create, but is not straight forward. In the used constant sum problem in this research there is no scale and no zero point. The collected data is therefore ordinal (Huber & Brandlow 2001; Survey Analysis 2015). This means that only the preference from one aspect over another can be used in statistical analysis. Points cannot be summed or subtracted as some participants score more extreme than others do. The rank can be used for analysis, but using the absolute data is scientifically irrelevant. Still, the absolute data is more insightful than the ranks.

Therefore both the rankings (ordinal data, to draw conclusion upon) and the average scores per group (insightful, but scientific not correct) will be shown in the results.

Differences between the groups
The standard deviations of the four groups per value are a measure for how far the opinions of the group differ. As the groups have different sizes the averages of the ranks are used and not the total dataset.

Differences in the group
The differences in the groups make clear how uniform the opinion or view of the group is. This is checked by investigating the standard deviations per value per group. Low standard deviations mean less different views. The average of the 8 values is a measure for the difference in view of the group. This test is done for the ranks and not for the absolute statements. With this the claim by Fraedrich & Lenz (2014) that the public has no clear collective image can be checked.

Another check that can be made with this information is if the definitions of the values are understood well. If values that are harder to grasp show a higher standard deviation this could indicate that they are not understood well. Simple values to grasp are safety or spending time differently. Values that are harder to understand are *self-determination* or *equality* in investments. If the standard deviations in the last two are higher than the first two this is an indication for badly defined values.

Scoring not common in VSD methods
The step of scoring values is normally not present in VSD or VAP studies. These methods stay qualitative, where the scoring step in this research is strongly quantitative. By letting many people from the four different groups fill in the questionnaire the differences between the groups can be researched. Besides that, is scoring with an online survey an effective and less time consuming way than interviewing people.

After this step the relative importance of the values per actor is clear and one value profile can be created. This answers the second sub-question: *what is the relative importance of these values per actor?*

11.2. Step 2: Specifying values to end-norms

The goal of this second step is to test if the workshop can be called a constructive dialogue. This workshop is held twice. Both with students and graduates who play the roles of the four actors. In the workshop, the participants first divide points over the 8 values. Just as is done in the offline questionnaire, but now together. The next step is to specify the 8 values to norms. According to Van de Poel (2013, p.265) specifying "helps to trace more precisely the value judgments and possible disagreements". This assumption is tested.

Set-up of the specifying workshop

Distributing points together — **Specifying values to norms**

80 → value → norm, norm
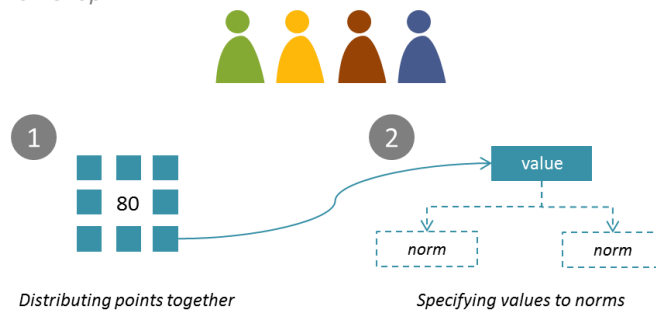
figure 11-6: The workshop with 4 actors consists out of 2 steps. First they divide points (like in the questionnaire), but now together. Next, the 8 values are specified to norms.

Where in the first steps value profiles are created, the second step is where the constructive dialogue takes place. The results of the questionnaire (chapter 12.1) show that there are differences between the groups, but also in the groups the differences are high. This high standard deviation in the groups was not expected and made the intended method[39] impossible. Therefore, this step was converted to this specifying workshop. Which afterwards might have given more insights than the intended Delphi method could give. Positive side of the Delphi method is that strength of personalities does not influence the outcomes (Linstone & Turoff 2002, p.4) as people need to write and do have interaction via the researcher. This is a point of attention of the current method. The facilitator will pay extra attention to this, and the transcripts will be analysed on this aspect, as this is also one of the requirements to have a dialogue.

Translating the values to norms

In his paper *translating values into design requirements* Van de Poel (2013) describes how values can be used in design. Values themselves are hard to use as design input. He explains that specifying them to norms, and then from norms to design requirements, enables them to be used in design. This "specification" (see figure 11-7) as he calls it, should be done with both moral knowledge and context specific knowledge. The public should bring in the moral knowledge and the experts should bring in the context specific knowledge.

Values — Norms — Design requirements — Specifying
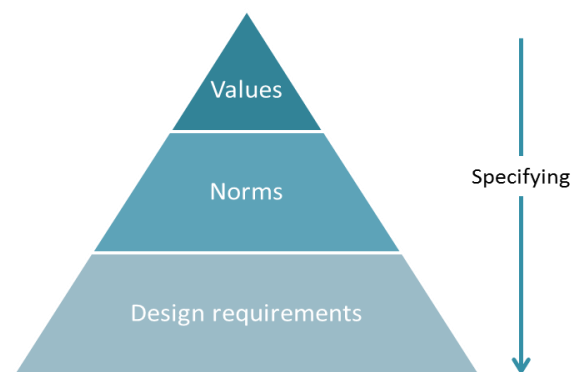
figure 11-7: the process of translating values into norms and norms in requirements in called specification (Van de Poel 2013)

An example of the specification is that the value *safety* is translated to *less accidents.* Van de Poel describes that it is even better to specify to so called end-norms. An end-norm is "a norm referring to

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[39] Instead of specifying a Delphi method was intended as step after the questionnaire. In the Delphi representatives of the groups should try to a common value profile in an online Delphi setting. Delphi methods are characterised by several rounds in which experts try to create one vision from their different standpoints. In the online Delphi everyone should change their own value profile to make it more look like the other value profiles. This would happen in multiple rounds. Positive side of the Delphi method is that strength of personalities are filtered out. Downsides is that it stays strongly quantitate, which is hard as the standard deviation per group is very high. Therefore a method is chosen which is both quantitative and qualitative, which has the advantage that more insights in value tensions are provided.

an end to be achieved or strived for" (2013, p.258). So *less accidents* then becomes *automated vehicles will cause 95% less accidents than current cars.* Here the norm is formulated as a goal and quantified.

The outcomes of this specifying workshop are not the main interest of this research. The most important result is the process of specifying. The method should provide insights in value tensions. Van de Poel (2013, p.265) explains that specifying "helps to trace more precisely the value judgments and possible disagreements". "Moreover a values hierarchy may be helpful in pinpointing exactly where there is disagreement about the specification of values in design". Where the value profiles from the questionnaire gave a global view on where the disagreements are, the specification should give more in depth insights.

In most cases specification is done with one actor group and experts (van de Poel 2013; Meijdam 2015). However, in this research representatives of the four actors together specify in one workshop. We hope this traces discussions on values even better. The role of the facilitator (the researcher) is to create a safe and equal setting (Verhoeffen & Kupper 2014), besides that he also has to provide knowledge if needed. As the group consist of only four people, the two tasks can be combined. For larger groups it would be good if the tasks are split up, just like is done in the TNO in-car-game (Van Noort et al. 2007). In the second session giving information is less needed, as two students there (playing the role of the government and car manufacturer) have more knowledge on automated vehicles. One of them is an ex-intern of an automation department of a car manufacturer, the other graduated from Transportation and Planning.

Constructive dialogue in a workshop
Representatives of the four actors will have a dialogue in the workshop. First, some information about self-driving cars is given to the participants. This will be similar to the introduction of the questionnaire. The next step is to warm-up by distributing points over the 8 values. This works the same as in the questionnaire, but now multiple actors should come to consensus. In this first step the negotiation starts.

In total three sessions are done. The test session is not taped. This session is used to check if the method works.

Test session	Only dividing points	4 students / graduates	Not taped, but analysed with participants
Session 1	Dividing points and specifying	4 students / graduates	Taped and coded
Session 2	Dividing points and specifying	4 students / graduates (more specific selection)	Taped and coded

For the first and second session government officials and employees of the manufacturers were contacted if they were willing to join the sessions. Several attempts are done, but no one was found willing to join. Therefore, all sessions are done with students or recently graduated students. Unfortunately makes this that the outcomes of the sessions are not valid because the students do

not know the values of the organisations they represent. To increase the reality of the sessions students with background information were found willing to join.

Together dividing points over the values (warm-up and common value profile)
The session starts with dividing the points of the 8 values. With this first step, the participants are warmed up and a common value profile is created. This profile can be compared to the survey results of the different participants.

Dividing the points can be done in different ways. In the sessions is tried to let the participants work together without political or strategical moves. Therefore is chosen to let the participants in the workshops figure out themselves how to come to consensus. Methods like one chip at the time per actor brings in strategical elements, which are make the atmosphere less constructive. In the test session is tried to let the actors figure out how to come to consensus. This let to good results. The participants are asked to "divide 80 points over the 8 values".

In the following two sessions every participant is given 10 chips to divide themselves. With the first 10 they give an indication about their standpoints. The participants are asked to underpin why they divide the points as they did. Afterwards the group gets 80 chips to divide together. Here the common value profile is created. A possible outcome of the workshops is that the four actors cannot come to consensus. After this step the third sub-question can be answered: *to what extent one common value profile be created can in a dialogue?*

Specifying the values to end-norms
In the second part of the session the values are specified to norms. The participants got an A0 paper, markers and some information about specifying. First the value with the most points will be specified. Next values where in the first round most discussion was on are specified. The facilitator and the participants choose which value these are. In the first session the participants are set in the lead for specifying. In the second session the facilitator took the lead, as the first session made clear more steering was needed. Due to time constrains not all values can be specified. After this step the fourth research question can be answered: *which value tensions become clear when the values are specified to design input?*

Workshop setting

figure 11-8: Set-up of the first specification setting. All participants indicate their preferences with another colour. Later the blue chips are used to form a collective vision. The mobile phone records the session.

Analysis of the data from the workshops

Both sessions are recorded and transcribed. As the sessions take long, the introductions and anecdotes are not transcribed. How the chips are divided is photographed, just as the A0's where the specification is made on. As the participants in the workshops are not the real actors, but students who play the roles the outcomes of the workshop are not valid. Therefore, the atmosphere is of interest. As this is the first time the method is performed we would like to see if it works. The method is compared with the criteria set in chapter 10.

Comparing the value profiles with the questionnaire

The first step of the analysis is to compare the value profiles with the questionnaire. This is done to see if the students played their role well. Of course, the value profiles can differ, as they are different people, and the standard deviation in the groups in the questionnaire is rather high. However, if the outcomes are very different the workshops should be rejected. For each workshop the sum of the absolute differences of the rank with the questionnaire are compared per actor (see equation 10). If participants differ much from the questionnaire the D-score is higher. If one participant or one workshop shows higher differences than the rest this workshop is rejected.

$$D = \sum \left| Rank_q - Rank_W \right|$$ (10)

Where:

D	=	*Difference workshop and questionnaire*
$Rank_q$	=	*Rank in the questionnaire*
$Rank_W$	=	*Rank in the workshop*

Mostly discussed topics

The transcripts will be analysed on which topics is most discussion. To do so, the transcripts are analysed on which topics most time is spend on. Most interest here is to the first part of the workshop, where points need to be divided. Here all topics are important, whereas in the second step we zoom in on one value. The outcomes of this analysis are compared to the results of the questionnaire.

Criteria for a constructive dialogue

Secondly, is checked if the developed method is a constructive dialogue. We test the method on three aspects mentioned in chapter 10: it should be 'constructive', it should be a 'dialogue' and it should meet the 'innovation specific criteria'. The 'innovation specific criteria' are inherently connected with the method and therefore will be checked in the discussion. The other two are explained here below.

For analysing the workshop on the criteria for the 'dialogue', we close coded the transcripts (Bryman 2012, p.569). This type of coding is used when proof for concepts need to be found in the transcripts. These concepts are the aspects mentioned in chapter 10, in table 10-1. Here they are translated to specific codes which need to be found in the transcripts. Not only criteria that make a dialogue, but also the opposite is researched, as that is sometimes easier to find and then can be exclude that this never occurred during the dialogue.

Codes from the definitions of Smalling (2008)	Opposite definition
Topic is set by participant	
Question asked to other participant	
Discussion with other participant	
Respect	Unresentful behavior
Respect for being different	No respect for being different
Equality in the discussion	Use of power position
Honest	Un-honest answer
Open about their interests	
Listen to each other	Not listening to each other
Help each other in formulating arguments	
Acceptable arguments	Use of fallacies or discussion tricks

Constructive elements in the dialogue

These criteria are only for the dialogue. For the second aspect 'constructive' which is defined as "aimed at influencing technological choice and design processes". Closed coding is used (Bryman 2012, p.569)to analyse the transcripts. In the transcripts is searched for elements where the step from values towards concrete technological changes are made. From this it can be seen if discussion is aimed at influencing the design.

Tracing value judgements

Thirdly, is checked if we can find what Van de Poel (2013, p.265) describes in his paper on specifying values to norms. He describes that specification "…. helps to trace more precisely the value judgments and possible disagreements". This is done by analysing the transcripts and comparing them to the outcomes of the questionnaire.

11.3. Origin of different parts of the method

The method is constructed based upon insights from different other methods. In figure 11-9 the method, with notes where different parts of it originate from, is summarised.

Overview of the method and where the steps originate from
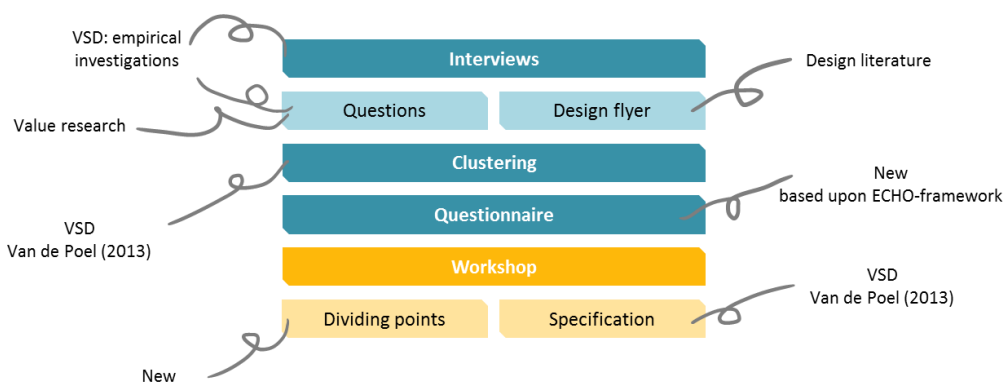
figure 11-9: The method with the separate elements, with an indication where the aspects originate from. VSD is value sensitive design.

The basis of the method is Value Sensitive Design and more specific on the empirical investigations of it (Friedman & Kahn 2002). Value sensitive methods in literature are often used and meant for one expert group and one laymen group (the public, the consumer) (van de Poel 2013; Friedman et al. 2002). Often a facilitating party is involved. In this research however, two expert and two laymen group are involved. Using multiple groups has been done before, for instance in Urban Sim (Friedman et al. 2013, pp.68–71) but is not common to do. Due to these multiple actor setting a questionnaire becomes attractive to get more insight in what different actors value. Besides this change to the VSD method some aspects from other methods are used. In the interviews a method originated from design and strategy (Osterwalder et al. 2014) is used. Based upon the same aspect as the questionnaire the workshop starts with dividing points. Where in VSD research the values and their interpretations stay qualitative, here they are made quantitative. Of course, making values quantitative does not totally respect the nature of values, but it gives a good indication and starting point for discussion.

12 Results

The last chapter explained the method (summarised in figure 12-2). In this chapter the results of the investigations will be presented.
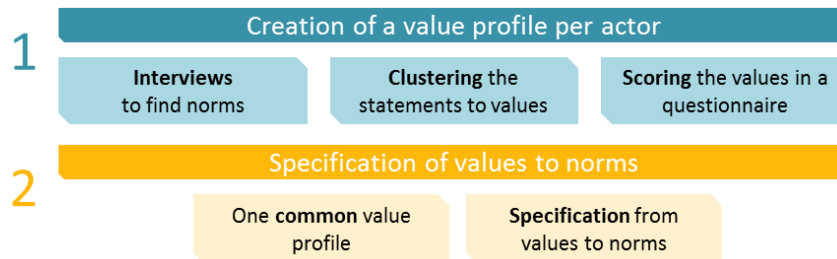
figure 12-1: The investigation starts with creating a value profile for each of the four actors. This is done by extracting different value from interviews and let the actors score them in a questionnaire. In the next step a workshop is organised where one common value profile has to be created and the values need to be specified to norms.

12.1. Results step 1: finding a value profile per actor

The goal of this first step is to find a value profile for the four actors: the government, manufacturers, consumers and other road users. This is done by interviewing them, clustering the statements from the interviews to values and lettering 144 respondents score the 8 values from the clusters on their relative importance. The different parts of this investigation will be discussed here below.

Interviews finding a longlist of norms

In total 6 interviews are done. Five to find the values and one to check if all values are found. In the next paragraph is elaborated on the check interview. The interviews took between 30 minutes and one hour. The semi-structured interviews contained a creative element which gave good results.

5 interviews
The five interviews are done with:
- A consumer
- A non-consumer
- A senior policy advisor of Rijkswaterstaat (member of the governmental working group on automated vehicles)
- Two automated driving researcher of a large German car manufacturer (one on driving assist systems, one on highly automated driving). This interview was done via the telephone.
- Two members of the ITS team of the ANWB (NGO)

Upfront three test interviews are done, these are not analysed for the results. The five interviews are coded, which resulted in 72 statements on automated vehicles. The transcripts of the interviews can be found in appendix I, the list with all codes can be found in appendix K .

Insights in tensions from the questionnaires
Especially the questionnaire and the workshops are meant to find tensions, but in the interviews the first tensions might also become clear.

From the interviews a few aspects stand out. First, many interviewees name the same aspects. Safety, less traffic jams and doing something else while driving are named very often. Each of the participants names these and states all these aspects are important. When is asked to rank them, people often find this difficult. The ANWB also names these aspects, but comes up with many more. They also value equality in investments, privacy or an automated vehicle accessible for everyone. Where consumers and other road users many name superficial aspects the ANWB goes one step deeper. Although everyone names an improved traffic flow, the manufacturer explains they cannot be held responsible for improving the traffic flow on their own.

What further can be seen is that groups show empathy for others. The non-consumer indicates that he wants automated vehicles to be stimulated, although he not got one himself. The consumer indicates that safety of others is one of the most important aspects of automated vehicles.

Creative element in the interviews
The interviews where semi-structured and contained a creative element. The start of the interviews (the questions and asking "why?") are normally used in other studies (Oppenhuisen & Sikkel 2000; van de Poel 2013; Meijdam 2015). The creative element (designing a flyer for your ideal automated vehicle) originates from design literature and is unique for value studies.

The creative element worked good in some situations and less in others. Especially the consumer, non-consumer and the government could express themselves better and came up with new values. The flyer also gave a first insight in the ranking of values per person. Downsides is that some people hesitate when they need to design something and feel more comfortable when questions are asked. The A4 paper with starting points is often used by the participants.

It seems that the creative part can be used in value research, especially in longer interviews where more time is available to warm up participants for a creative part. Besides this, it has most potential for VSD research, as this is used for new technologies. Probably the method works less for value research for current products or situations, as than imagination is less of importance.

Clusters: eight values are found
The researcher and 3 experts clustered the 72 normative statements to 7 values. After the clustering the values are compared with literature in order to see if these values could also be found in literature. From literature one extra value is added.

7 values from interviews, 1 extra from literature
From the interviews 72 statements (both values and norms) are collected. These 72 statements are clustered to 7 values. In this session three experts first clustered the statements on their own, whereafter the experts and the researcher combined the insights to one clustering. The researcher had the final voice in clustering and finished the value clusters. The values are summed up in table 12-1.

A few statements from the interviews are not taken into account in the clusters. In total 9 statements are left out: 3 of them were not specific enough, 2 were on the process of the innovation and not on the form of automated vehicles (van de Poel 2013, p.263) and the other 5 were not clear enough, not

relevant for level 3, not on automated vehicles or a requirement instead of a value or norm. In the appendix K the statements which are left out and reasons for that are summed up.

table 12-1: The 8 values used in this research. The first 7 are derived from the interviews and clustering. The 8th value (security) was several times explicitly mentioned in literature and therefore added.

Value	Definition	In literature*
Spending time differently	The driver can do something else while driving.	A
Safety	Less and less serious accidents	A, B, C
Higher traffic flow	Faster and with less emission from A to B	A, B, C
Liability	There is clear regulation and the driver is not liable when the system is on.	A, B, C
Accessible for everyone	Every group in society (also novice drivers or elderly) can understand and driver automated vehicles.	C
Self-determination	The driver, and no other party, can decide on the speed, route and data use.	B
Equality	All road users should benefit from the introduction of automated vehicles, or their position should remain the same.	B
Security	Automated vehicles are harder to be hacked, misused or stolen (both data and the vehicle).	A, C

* A: Freadich and Lenz (2014) researched reactions under news websites in Germany (from Bild to the Süddeutsche Zeitung). Reactions are clustered in clusters made by the researchers. B: Howard and Dai (2014) 107 likely adopters in Berkley, clusters made by the researchers. C: KPMG (2012; 2013) have made a consultancy report on automated vehicles and cluster the advantages.

Studies used to check the value clusters
To check if the clusters make sense, the clusters are compared to literature. There are several studies where 'aspects' or 'features' of automated vehicles are researched. The studies are hard to compare, as mostly level 5 is researched and the 'aspects' they use have no empirical or theoretical ground. Still, all 7 clusters can be found in literature. However, an eight cluster was also mentioned often in literature: security. This aspect is not mentioned in the interviews, but is often named in literature (Schoettle & Sivak 2014; Kyriakidis et al. 2015; Tech Times 2015; Wilmink et al. 2014).

Value profiles: questionnaire to 144 Respondents

After the clusters are made a questionnaire is sent to representatives of the four actor groups. 144 respondents filled in the questionnaire. They concluded that safety is the most important value. The value profiles of the groups show differences. Also striking is the high standard deviation in the groups.

Type of respondents: young, higher educated with a technical background
144 respondents filled in the questionnaire. The first respondent filled in the questionnaire on 17th of September 2015 and the last the 19th of November 2015. How the respondents are distributed over the four actor groups, age groups and online and offline survey is shown in figure 12-2.

Amount of responses per:

Actor group — *Age group* — *Online / offline*
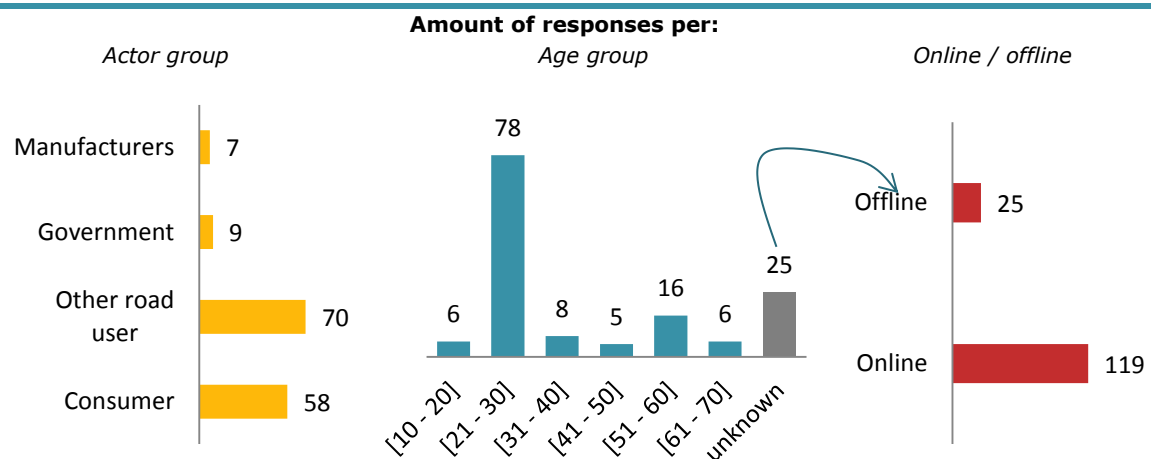
figure 12-2: The questionnaire is mainly filled in by customers and other road users, mostly online and the there is a large share of people in the age range between 21 and 30. As the questionnaire is distributed via friends and family there will probably be a bias to higher educated people living in the province of South-Holland in the Netherlands.

Online questionnaire

The online questionnaires for the public (other road user and consumer) are distributed via friends, family, and Facebook. As e-mails are forwarded and Facebook is used as medium the response rate cannot be calculated. Due to the distribution method the sample will contain a bias to higher educated people living in South-Holland with a technical background. As a result of these biases and the relative small amount of people having filled in the questionnaire the survey is not representative. However, it gives a good indication and enough respondents to test the method.

The questionnaire for the government and manufacturer are more targeted. Government officials who filled in the questionnaires work on policies of self-driving vehicles at Rijkswaterstaat, the ministry of I&M, RDW or a province. The car manufacturers are manufacturers from America, Germany, Sweden and Japan. All of them work in the research and development departments on a form of vehicle automation.

Offline questionnaire

Next to the online questionnaire an offline version is used. At the *Back to the future festival* of Connekt 25 participants are asked to distribute points over the 8 values. This festival was chosen as many government officials would be here.

figure 12-3: An example of the filled in offline questionnaire.

Quantitative value profiles per actor

As explained in the method chapter, the sum of the points is not scientifically correct to use, as the data is ordinal (no scale and no zero point). Still, the absolute data is easier to interpret than the ranks. Therefore both the rankings (ordinal data, to draw conclusion upon) and the averages scores per group (insightful, but scientific not correct) are shown in figure 12-4.

Preference for the values: absolute (top) and their rank (bottom)
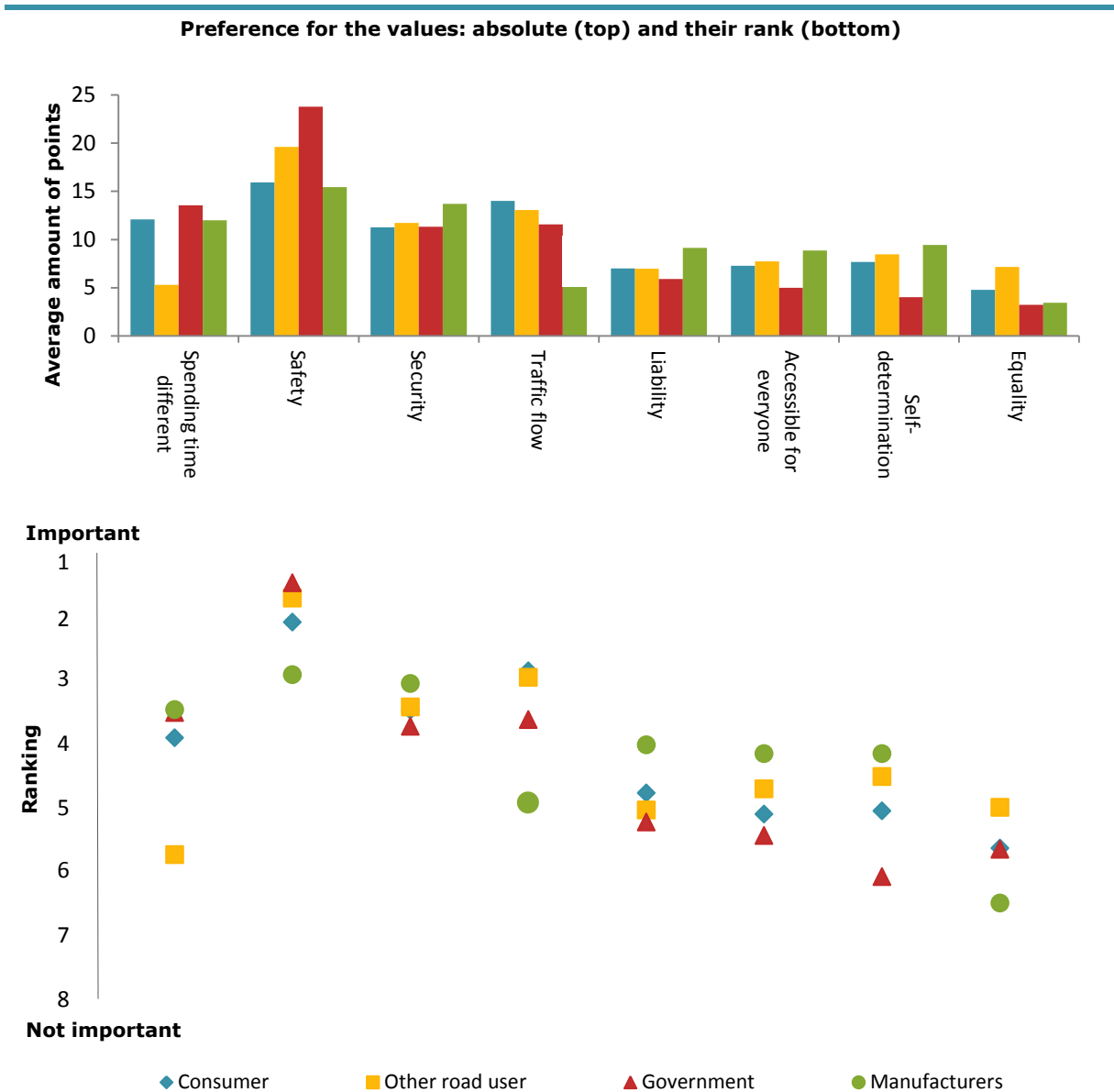
figure 12-4: The two graphs show the results of the constant sum question. The graph above shows the average amount of points given per value per actor group. The bottom graph shows the average rank per actor. The same results are presented in another way in figure 12-5 on page 145.

Differences in value profile

What can be observed from bottom graph of figure 12-4 is that *safety* is found the most important aspect of self-driving vehicles. All 4 actors acknowledge this. Other studies also find *safety* as most mentioned aspect (Fraedrich & Lenz 2014; Howard & Dai 2014; Casley et al. 2013). However, manufacturers find this aspect somewhat less important than the other actors. *Security* and *traffic flow* are the two second most important aspects. These three mentioned aspects all lead to a benefit

for all users: a system optimum. However, the car manufacturer is less interested in optimising *traffic flow* than the others. They indicate that if you could do something else while driving the time is not of importance, or that this is not possible to realise by one manufacturer[40].

Spending time differently is found important by the user, the government and the car manufacturer, but less by the other road user. This is logical, as other road users do not experience any benefits of this aspect. However, the amount of points they give is not zero. The other road users indicate that in the future they also might like to buy a self-driving vehicle and that they see economic benefits. The economic aspect is also mentioned by the government. Earlier research of Fraedrich and Lenz (2014) shows that people not only find aspects which have benefits for themselves important for future automated vehicles. They have some sort of altruism.

It seems that the four aspects on the right are less important than the left four. It can be seen that especially the car manufacturers likes to have a clearly arranged *liability*, cars *accessible for everyone* and a high *self-determination* for the driver. The definition of *liability* in this study is that the liability is not with the driver in case of an accident when the system is on. Google, Mercedes and Volvo, among others, stated they are liable if the system fails. The CEO of Volvo explained to "accept full liability whenever one if its cars is in autonomous mode" (Gorzenlany 2015, p.1). The other three actors see *liability* also as an important value, some indicate that this is a "boundary condition for market introduction".

Accessible cars for everyone is found important by manufacturers, probably as they can sell cars if more people are able to use them. The other actors score this aspect slightly less. *Self-determination* is found important by all actors, except for the government. The other three actors however find *self-determination* of the driver important for different reasons. Some consumers and manufacturers explain they always want to let the driver be in charge of the vehicle as driving can be fun. Others name data ownership and privacy as important aspects of *self-determination*. This aspect is only mentioned a few times in the underpinning of the choices in the questionnaire. McKinsey (2015, pp.6 & 17) concluded from an international questionnaire that "only a quarter of customers categorically refuse to let OEMs use their driving data." Other road users describe that they do not trust the computers and therefore the driver should always be in charge. It seems that value of *self-determination* had to be split-up to give more clarification. This is done in the second workshop.

Equality in investments is only found important by the other road users. Logical, as they do not experience many benefits of, for instance, subsidies on automated vehicles. However, also other road users explain that if automated vehicles have societal benefits they might be subsidised. Yet, they do not want that the luxury of automated vehicles is subsidised instead of the system, as now happens for electric vehicles according to some of the respondents.

An overview of the value rankings can be found in figure 12-6.

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[40] This is not only indicated in the questionnaire, but also in the interview.

Relative importance of the values

	Consumer n=58	Non-consumer (n=70)	Government (n=9)	Car manufacturers (n=7)
important	Safety (1.9)	Safety (1.5)	Safety (1.2)	Spending time differently (2.7)
	Traffic flow (2.6)	Traffic flow (2.8)	Spending time differently (3.3)	Safety (2.8)
	Security (3.3)	Security (3.2)	Traffic flow (3.4)	Security (3.0)
	Spending time differently (3.8)	Self-determination (4.4)	Security (3.6)	Self-determination (3.7)
	Liability (4.6)	Accessible for everyone (4.6)	Liability (5.1)	Accessible for everyone (3.8)
	Self-determination (4.9)	Liability (4.9)	Accessible for everyone (5.3)	Liability (4.2)
	Accessible for everyone (5.0)	Equality (4.9)	Equality (5.6)	Traffic flow (4.7)
	Equality (5.6)	Spending time differently (5.6)	Self-determination (6.0)	Equality (6.3)
unimportant				

figure 12-5: Relative importance of the values per actor. The same values have the same colours. After the actor names the amount of respondents of the questionnaire are mentioned. The number behind the value name is the average rank for the stakeholder group.

Time spent different, safety, traffic flow and self-determination lead to most discussion

In figure 12-6 the results from the questionnaire are schematically shown. The position indicates the importance, the colour the level standard deviation. From the questionnaires (and also the sessions) it can be concluded that *safety* is the most important value. Followed by *security* and *traffic flow*. The *time spend different* and *liability* are next. An *accessible car for everyone*, *self-determination* and *equality* of investments are the least important.

It can be seen that most disagreement is on *spending time differently*. Here especially the non-users and government are on one side, the car manufacturer and users on the other. *Traffic flow* is found important by the government and the public and less by the car manufacturers. For *safety* the car manufacturers find this less important than the other three actors. *Self-determination* is found important by car manufacturers, somewhat less by the public, and unimportant by the government. Interesting are points which manufacturers or the government do not find important, but are valued by others. These points are most likely to get less attention, as Timmer & Kool (2014) explain that the public is not involved at this moment. The aspects where this tension arises are: *traffic flow (by the manufacturers)*, *self-determination (by the government)* and to a lesser extent *safety (by manufactures)*. The position of safety is debatable here as many manufacturers state in the press that they find this important (Gorzenlany 2015; Google 2015a). A high in-group standard deviation indicates that not all manufacturers agree (see table 12-3).

Values ranked on importance, the colors indicate the amount discussion
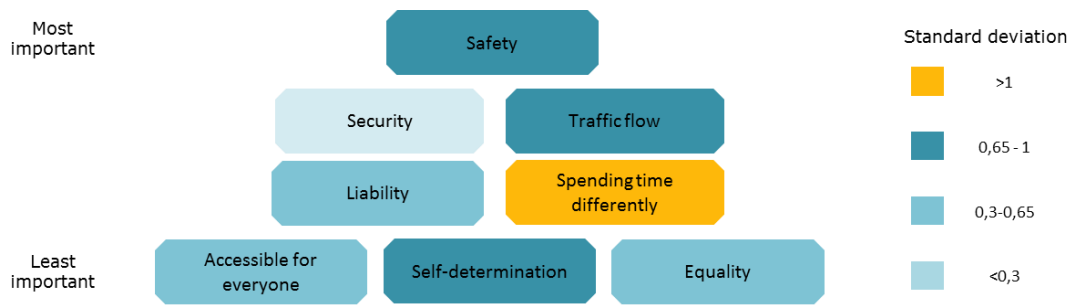
figure 12-6: The position of the value indicate the average importance, the colour indicates the standard deviation between the averages of the ranks of the groups in the questionnaire. This shows the amount of disagreement between the groups.

Difference *in* the groups is higher than *between* the groups

In order to see if a group has a unambiguous opinion the standard deviation of the groups are investigated. If the standard deviations of the ranks in the group are compared it can be seen that these are higher than the differences per actor group (see table 12-2). The differences in the group are even higher than the differences between the groups.

table 12-2: the average standard deviations for the 8 ´values´ per actor group.

	Standard deviation absolute [point]	Standard deviation rank [rank]
Consumer	6,5	1,8
Other road user	5,8	1,8
Government	6,1	1,5
Manufacturers	7,8	1,9

This does not imply that there are no differences between the groups, just that in the groups there are larger differences. There can be several reasons why this is larger. First, the opinions in the group can differ. Secondly, this high standard deviation could also mean that people answered the questionnaire while having a different interpretation of the values (as Fraedrich & Lenz 2014 explain). A third option is that the values are misinterpreted. This would mean that the questionnaire would not be valid. This last aspect is checked by investigating the standard deviations per value. These are shown in table 12-3. If the definitions are unclear the standard deviations on this value would be high. Easier values to grasp as *spending time different, safety* or *security* and harder definitions as *self-determination* or *equality* do not underpin this conjecture. For instance *spending time differently* is a very clear definition, which has a high standard deviation. So, probably the people in the groups have different opinions about values. Nevertheless, that some people understood the definitions in another way can still be the case.

	Consumer	Other road user	Government	Car manufacturer	Whole sample
Spending time different	2,3	2,0	1,9	1,9	2,3
Safety	1,2	0,9	0,4	2,2	1,0
Security	1,6	1,8	1,9	2,0	1,8
Traffic flow	1,9	1,7	1,8	1,8	1,8
Liability	1,8	2,0	1,9	1,5	1,9
Accessible for everyone	1,9	1,8	1,4	1,7	1,8
Self-determination	1,9	1,9	1,3	2,8	2,0
Equality	1,7	2,1	1,7	1,2	1,9

Quality checks on by checking the qualitative data

Other quality checks are done by means of the qualitative data. These checks are done to see if the respondents understood the questionnaire The data of the last question of the survey, where people indicate why they made this distribution and the 'any comments?' data are analysed.

After filling in the constant sum problem the respondents are asked why they scored the two highest values the highest and the two lowest the lowest. With this information it can be seen if people understood the values and filled the questionnaire in as it was meant. There are a few points of discussion for the questionnaire:

Clear survey	The respondents often indicated in the "any comments?"-box that they liked the survey set-up, that it was short and that the movie gave a clear explanation about what was asked. Only few negative points where expressed, but the ones that were mentioned are that the constant sum question is hard to answer and that it was hard to picture yourself as another road user.
Ambiguous defined values	The value *self-determination* has many aspects, of which some might contradict, as already is indicated in the previous paragraph. Privacy, data ownership, fun of driving and distrust of the automating system are mixed up in this value according to the qualitative data. In one of the offline questionnaires was indicated that perhaps traffic flow would have gotten more points if sustainability was more clear available. As this aspect was only once mentioned in the interviews this was seen as a small aspect.
Taking some aspects for granted	The intention by which people fill in the questionnaire differs. In the offline questionnaire someone explained not to give safety points as he expected this to be arranged before market introduction. In a large expert meeting this problem was also mentioned (Alkim & Veenis 2015, p.33). However, it was the intention of the questionnaire to also capture these aspects. This specific questionnaire was taken out and the qualitative data is scanned if more people filled in the questionnaire with this intention. None were found, however, not all people indicated why they scored an aspect as they did.
People representing	The government officials and the manufacturers are explicitly asked to fill in the questionnaire according to what their companies would fill in. However, probably

organisation	personal opinions are mixed with their corporate or institutional opinions. One respondent indicated explicit that it was his view, not the one of his company. His survey is interpreted as one of a consumer.

It seems that setting up a questionnaire to score values is a delicate task. Especially the definition of the values and explaining with which intentions the questionnaire should be filled in is hard to explain to respondents. Both have gotten much attention, but still can be improved.

Findings based on the different value profiles

With the results of the questionnaires and the interviews in hand some first findings can be extracted. What should be kept in mind is that the sample is small, which makes it hard to draw conclusions.

Large differences in groups

The first thing that is striking is that the standard deviations in group are rather high. This indicates that within a group different opinions are present. For manufacturers these might be different brands with different visions, for the government (where the standard deviations on the ranks are the lowest, but still 1,5 rank) this could indicate that different institution find different aspect important. For the public this shows that there is normative diversity (Verhoeffen & Kupper 2014) among the public. This means that there are different people with different viewpoints. It might be interesting to research if different groups within the groups can be found. The Q-methodology (Brown 2000) can be used to differentiate the groups and create personas. Another reason for a high standard deviation are different interpretations of values. Yet, the standard deviations contradict this.

Conflicting value profiles

Secondly, the value profiles of the different actors do not differ much. At maximum 2 ranks difference. However, there are two striking differences: 1) Safety is indicated as most important aspect, however, car manufacturers score this aspect less than the other groups. Since car manufacturers have most influence on safety this is a point to highlight. Reassuring is that the standard deviation for manufacturers on safety is very high, which means that not all manufacturers think the same here. 2) A same pattern can be seen in traffic flow. Three actors other score this value high, but car manufacturers are less interested in this point. Therefore a way should be found for the public and government to incorporate these values in the final design.

12.2. Results step 2: specifying values to end-norms

The second step consists of two workshops and a test workshop. In these workshops students play the roles of the government and car manufacturer. Since not the actual actors sit around the table but two of the roles are played by students the actual outcomes of the workshops (a common value profile and values specified to norms) are not the main interest. A couple of aspects are tested: first, the value profiles of the workshops and questionnaires are compared. Secondly, the transcripts are analysed to see on which values is most discussion. Thirdly, is checked if the method can be called a constructive dialogue according to the criteria set in section 10.4. Lastly, is checked if what Van de Poel explains in his paper on specification, can be seen in this empirical setting.

Comparing the workshops and the questionnaire

To see if students played their role well, the questionnaires are compared to the workshops. What can be seen from figure 12-7 is that there are no outliers to the top. Almost every student who played a role differs equally from the average of the questionnaire. Except for one person in the test workshop, who differed only 3,5 point in total with the questionnaire. Another noticeable aspect is that in workshop round 2 the participants are selected less randomly. Here an ex-intern of an automotive company played the role of the manufacturer, his profile differed not more or less than other participants. All findings lead to the conclusion that there is no reason to reject any of the workshops.
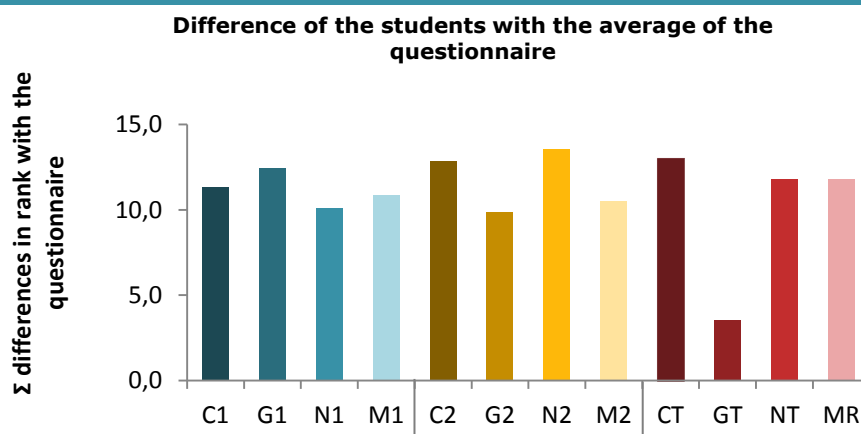
figure 12-7: Differences for the students with the questionnaire per session. The Y-axis shows the sum of the differences in rank with the questionnaire ($=\sum |Rank_Q - Rank_W|$). C = consumer, G = government, N = non-consumer, M = manufacturer. The second index is the session (1=the first, 2= the second, T = test). A lower score means more overlap with the questionnaire.

The created value profiles
In the two sessions and the test session value profiles are created. The common value profiles are shown in figure 12-8. The results of the common value profiles look similar. They are also comparable to the results of the average of the questionnaires shown in figure 12-4 on page 143.
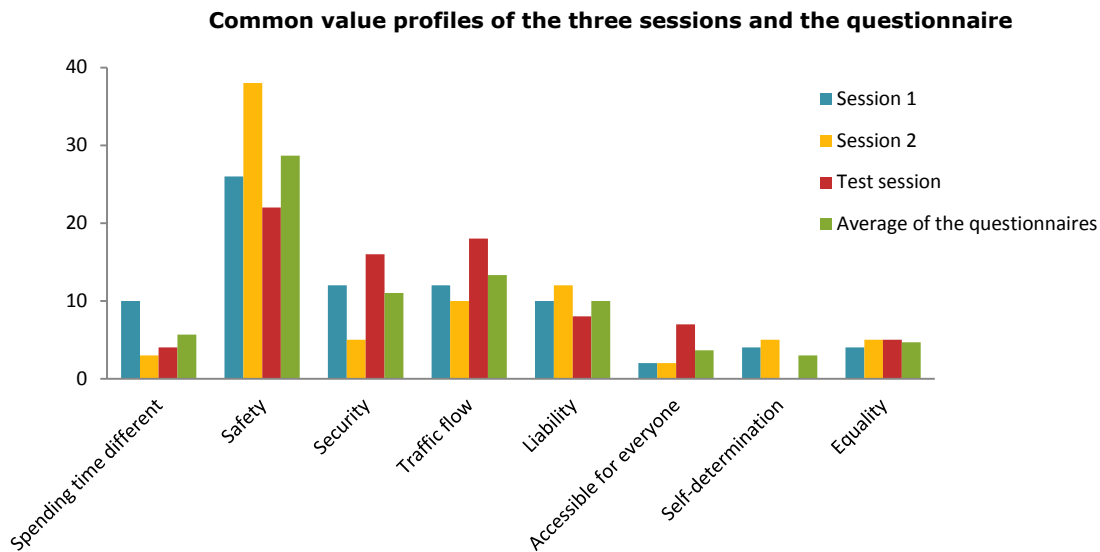
figure 12-8: The three common value profiles are compared to the average of the 4 groups from the questionnaire. The sessions differ, but still show with the average of the questionnaires.

From the questionnaires and the first round of the workshop it can be concluded on which values most disagreed is. The questionnaire gives quantitative data, where the workshops present qualitative data. The different insights enrich each other. The questionnaire is done among more people and the respondents are the 'real groups' and not students who play a role, so the outcomes of the questionnaire are weighted heavier. The results of the questionnaire are shown in 12.1. This questionnaire shows that most discussion is on *spending time differently, safety, traffic flow* and *self-determination*.

Analysis of the transscipts

The transcripts of the workshops are analysed on several aspects. They are analysed upon the discussion per value, if it can be called as a constructive dialogue (the criteria from chapter 10.4) and if what Van de Poel (2013) explains in his paper can be confirmed empirically.

What should be kept in mind is that the workshops are done with students. From these workshop can't be concluded that this method works or is a constructive dialogue, only indications can be given. These analysis also show how in future research this analysis can be performed.

Discussion per value

The questionnaires explain that most discussion should be on *spending time differently, safety, traffic flow* and *self-determination*. In the workshops a slightly different pattern can be seen. The transcripts are analysed and what can be seen is that most discussion is about *spending time differently, traffic flow* and *self-determination.* Especially *safety* (which had a high standard deviation in the questionnaire) and *security* are the topics were the actors immediately agree upon. Also the specification of *safety* or *security* goes with less discussions that the other values.

table 12-4: values where most discussion was on in the workshops.

Value	Discussion
Spending time differently	In both workshops the car manufacturer and the consumer (to a less extent in the second workshop) would like to have more attention to time spend differently. The government and other road users do not dislike the aspect, but like to see the points go to other aspects. There is a difference in priority instead of a difference in desire.
Traffic flow	In all workshops the car manufacturer showed no interest in this aspect. The user in both workshops had no strong opinion. The government and non-user indicated to value this point strongly. The car manufacturer indicated that probably should be responsible for this aspect, but did not feel the priority as much as others did.
Self-determination	Especially in the second workshop much discussion was on self-determination. Partly due to different opinions, partly due to the difference in interpretation. Some actors (user and non-user) would like to see much *privacy*. Others would like much *autonomy* for the driver (user and car manufacturer).

The difference between the questionnaire and the workshop can be explained by that in the workshop arguments are given. If people hear arguments and do not have a strong opinion themselves they are likely to follow. In the questionnaires everyone fills it in without contact with others, this means opinions are probably more extreme. Another differences can be that the real actors have a different value than the students playing their role.

Constructive dialogue

In chapter 10.4 criteria are set which the method should meet to be a constructive dialogue. This is done by analysing the transcripts of the two workshops on the codes named in 11.2. Appendix O shows the transcripts and in appendix P the codes with quotes are shown. Here below the most striking points are discussed. What should be kept in mind is that this is done with students, with real actors of course other outcomes can arise.

Can the workshop be called a dialogue?

What can be seen from the coding[41] is that *topics are set by the participants, questions are asked* and *there is discussion.* All participants are free to do so, and do this. These codes are indicators for equality in the discussion. The next aspect 'mutual trust and respect' is hard to derive from the codes, as showing *respect* is hard to analyse from transcripts. Therefore also the opposite is researched: being *un-respectful*. This type of behaviour is never found in the transcripts. The following aspect is 'openness', this can be seen many times, especially in the first part of the workshop. Participants are strongly *open* about their values and standpoints. They even *help each*

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[41] The statements written in italics are codes from the transcripts.

other in formulating arguments or help each other with coming up for with arguments. Also good to see is that the students have a constructive mind-set and cooperate instead of are in competition. The best example is the non-consumer who explained in the first session: "Let's search common ground. First more points there [on safety] and there might be points which no one scored yet, but we now want to score together". The argumentative quality is fine, although sometimes is made use of power positions. For instance when the consumer stated: "If I pay for the car, I want to get something for my money. Otherwise I'll stay in my current car" (session 1). The reflective nature of the participants is hard to assess as the workshops are done with students. Still on 4 of the 5 criteria the method can be called a dialogue, the fifth is impossible to investigate.

Can the workshop be called constructive?
Besides the criterion of a 'dialogue' the workshop should also be 'constructive', which is defined as "aimed at influencing technological choice and design processes" (see chapter 10.4). To do so, the transcripts are open coded. What can be seen is that the method makes that the values become *practical* and even *new ideas arise* in the workshop. Especially when the values are translated to norms and end-norms are formulated the discussion is aimed at influencing technological choices.

Tracing value disagreements
Van de Poel (2013, 265) explains that the method "helps to trace more precisely the value judgments and possible disagreements about them, even it does not offer a way to solve these conflicts". Both the *value judgements* and the *disagreements* on them become clear from the workshops. Different groups judge aspects differently. In the second session the non-consumer raised the point that he would like to add the 'the feeling of safety' to the value of *safety*. In the case of *self-determination* some parties value privacy, whereas other value the autonomy of the driver.

The workshops show that both aspects Van de Poel mentions (value judgements and discussion) in his paper are also found in an empirical setting. Moreover, he explains that "it does not offer a way to solve conflicts", the workshop indicates that this can be a measure to help to solve conflicts.

Role of the facilitator
The facilitator had a dual role in the sessions: facilitating the workshop and giving extra information about self-driving cars. Both roles differed in the two sessions. In the first session the discussion was less steered, on purpose. This sometimes led to chaos or discussions which did not contribute to the goal of the workshop. After the first session it seemed that a stronger facilitator was needed, which was tried successfully in the second session. This also lead to more specific results. Still, the first group came with more original ideas to relate the technology to. For instance *security* was specified to "*on the same level as a bank*". In the second session more traditional relations were used, but the outcomes were more quantified and more aspects were discussed.

The role of giving extra knowledge was less needed in the second workshops as there two participants were present who had more knowledge about automated vehicles. Normally in other workshops two different persons have the role of the facilitator and knowledge giver. As the group was small, the discussion was easy to manage and there was time left to give extra information.

13 Discussion

In this chapter will be zoomed out to have a more wider view on the research. First, the method will be discussed. Here we will start with the discussion of the individual steps to follow with more general notions. In the second part of the discussion the two development paths are linked to the outcomes of the survey and workshop to discuss their social desirability. The chapter finishes with an outlook to a more responsible future of the automated vehicle innovation.

13.1. Discussion on the method

In this thesis is researched if the used method can help to reflect on the social desirability of different scenarios of the automated vehicle innovation. The method is based upon Value Sensitive Design and especially its empirical investigations (Friedman & Kahn 2002). The method is extended with insights from outside of VSD. The creative part of the interviews or scoring of values are examples of this.

The method consists of two parts. In the first part (the interviews, clustering and questionnaire) the different actor groups are asked to form their own utopian view on automated vehicles. In the next step, the workshops, they are asked to form a utopian vision together (the game of dividing points together) and then to make to utopian view somewhat more concrete.

Discussion on the individual steps

The individual steps of the research are discussed briefly. In the next section more general aspects which hold for all steps are discussed. In figure 13-1 the method is shown. Besides the steps also comments where the method originates from are shown. Especially the elements which are novel or used in a different context will be discussed more elaborate.

Overview of the method and where the steps originate from
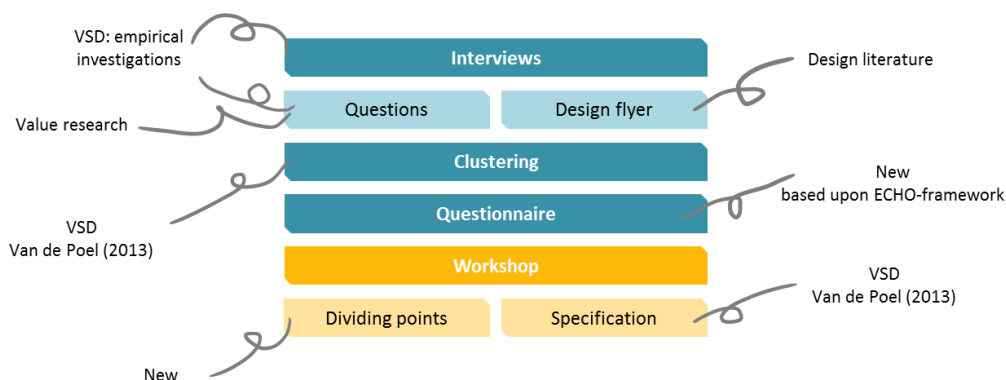
figure 13-1: The method with the separate elements, with an indication where the aspects originate from. VSD is value sensitive design.

Interview: did not cover all values, but the creative part led to interesting results
Based upon the empirical investigations of VSD interviews are done. Not all values are found by the interviews; literature added the value *security*. Probably a combination of many techniques is best to find all values at play. Value Sensitive Design literature also argues for doing an empirical, technical

and conceptual investigations and to iterate between them (Friedman et al. 2013, p.59). Whereas this research mostly focusses on the empirical part and does one iteration with literature.

In the interviews one novel element was tested: the drawing of an ideal self-driving car. The method originates from design literature (Osterwalder et al. 2014). Letting participants design their flyer led to interesting results for value research and is applicable for other research. The largest advantage is discussion becomes more explicit and specific as participants have to write and draw.

Clustering: not mutually exclusive, but the values seem to be collectively exhaustive
Clustering is a step that uses the output from the interviews, but also common knowledge to cluster. This makes it hard to reproduce the same outcomes in another session. However, due to underpinning the clusters with literature and making the clusters explicit it becomes "more systematic, […] explicit, debatable and transparent" (van de Poel 2013, p.265).

The workshop and to a less extent also the questionnaire, made clear that the value clusters give some problems. The values have relations with each other (e.g. safety and security) or capture different aspects in one value (self-determination: privacy and autonomy). The workshop also make clear that some values have a direction. Safety for instance has a similar direction for everyone (an extra point for safety has the same outcomes for all actors), but equality is seen different for the users as for the non-users (an extra point means less investments for automated vehicles and more in other infrastructure). This gives problems in the discussion with multiple participants. Nevertheless, the questionnaire did not show a higher standard deviation on more ambiguous values. Still, the value definition can be improved, but probably there will stay discussion on the values for all definitions. The clusters can be called Collectively Exhaustive, but Mutuality Exclusive stays a problem (MECE) (Rasiel 1999).

Questionnaire: constant sum problem works, but there are biased and small target group
The questionnaire gave insightful results: value profile for different actors. Which is novel in value sensitive design research. The respondents liked the set-up of distributing points (constant sum problem), but if it is more preferable than ranking is hard to say. The amount of respondents of the questionnaire is small (n=144) and has a bias to young higher educated people. Besides that, do ambiguous value definitions might have given some errors. However, there is no quantitative evidence for that. To conclude, it can be seen that this type of method works to create value profiles for different actors.

Workshops: constructive and a dialogue but it takes long
For the workshops should be clear that they are done with students and not with the real actors. This means that the exact outcomes of the workshops are not valid. The most important result is the process, which is still a welcome outcome as this is the first time this type of workshop is tested. In chapter 10.4 criteria are given for the workshop. As shown in the results (12.2) can the workshops be called a 'dialogue' and 'constructive'.

The first part of the workshop, the division of the points, makes that people need to be open about their interests and that people directly have to state their interests. In the second part (the specification) the values, which are still rather vague, become more clear. The group has diverse views, but creates mutual understanding in the first round. This is highlighted in both workshops by

the participants themselves. So, the first step creates an open setting, which is needed for the second part of the workshop. It also can be seen that there is empirical evidence for what Van de Poel (2013, p.265) explains in his paper on specifying values, this step "helps to trace more precisely the value judgments and possible disagreements".

Also striking is that new ideas arise. Nooteboom et al. (2007, p.1016) describe that there is "an inverted U-shaped effect of cognitive distance on innovation performance". Non-diverse groups are less creative, a too large cognitive distance also makes uncreative. The most creative are diverse groups (also explained by Cuppen 2012) who "share sufficient mutual understanding". Nemeth et al. (2004, p.365) explain that especially in conflicts new ideas arise. Van den Hoven (2012), but also Van de Poel (2015), indicate that in case of moral overload (too many conflicting values) innovation can open new doors. Especially, when these moral values are made explicit, as was the case in this workshop.

Practical aspect is that the specification takes long (around 30-45 minutes per value and maybe more if all aspects are taken into account). Besides that, it becomes clear that specification is no multi-issue game (de Bruijn & ten Heuvelhof 2008). In such a multi issue game all issues are discussed at once. If there is disagreement about an issue a losing party can get its way on another issue. A multi-issue game can stimulate stranded negotiations.

Discussion on the method in general
Where in the previous section the different steps were discussed separate does this section discuss aspects that are more general.

Discussion points which hold for the whole method
The method now is done with 4 actor groups, however, as is explained in the introduction, only the most important groups are used. The method could be extended with other groups. Besides that, there should be a higher diversity in the groups (Cuppen 2012). At this moment the questionnaire and the workshops biased are to higher educated and young people. Also more people and more tests are preferable. Now we have indications that the method works, but the sample of the workshops and questionnaires is too small to make bold statements.

Besides that, the people who are interviewed and surveyed are not the organisations themselves, they are asked to represent the organisations. There can be differences between their statements and the companies vision. For the public this problem does not arise, as there is no common vision of the public. To get more insight in the different parts of the public personas can be made based upon the value profiles (Brown 2000). For the car manufacturers a similar problem arises, here not every person has a different vision, but every company. Multiple people of one company could be interviewed to check the assumption. For the government it is probably easier, here are different institutions but they have a more aligned vision. However, the questionnaire shows different profiles for all government officials.

A third discussion point is the usefulness of the outcomes. The outcomes of the method are now the first steps of a Value Sensitive Design approach, however, there is no design made. It should be

tested if the outputs of the method can lead to a design, or if the designers of policies makers for automated vehicles find the values too restrictive to work with.

The last point is that values and especially their relative importance change over time (Abramson & Inglehar 1995). This means that this every 5 or 10 years this type of research should be repeated.

Representatives used in the study
In this study representatives of larger groups are investigated. To do so two main assumptions are done: 1) The people themselves are a good representatives of the public (consumers and non-consumer). 2) People working with automated vehicles at the government or manufacturers are best in translating the institutions mission and goal to context specific values for automated vehicles. They will be discussed both.

The people themselves are a good representatives of the public (consumers and non-consumer)
As this research investigates values of people (their fundamental ethical principles) it is most logical to investigate what the people themselves think of an innovation. Representatives, such as interest groups, mostly represent one value strongly and ignore others. The ANWB is a representative of the car user, so could be investigated. They are interviewed to create a longlist of values, but for the more subtle differences the people themselves need to score the values.

It can be seen that the ANWB comes up with more and deeper values (equality in investments or cars accessible for everyone), which is a very welcome addition. However, as the standard deviations are high in the two groups of the public it is hard for a representative to express this.

Another aspect is that for instance the ANWB (see interview) and the American consumer Watchdog (Tech Times 2015) have stronger opinions that the public has. Where the Watchdog has a strong view on privacy in the Tech Times, this research and an international McKinsey survey do not find many consumers having a problem with privacy and automated vehicles. This does not mean the Watchdog exaggerates it, it expresses its view on one value, where in this research multiple values are of interest.

As the relative importance of values is investigated, which is very personal, and the public values different aspects (high standard deviation) it is a good choice that the people are investigated and not the representatives.

People working with automated vehicles at the government or manufacturers are best in translating the institutions mission and goal to context specific values for automated vehicles
For this research we need employees representing the institution they work for, and translating the mission of the institution to values related to the automated vehicle innovation. As top managers (in companies or ministries) have multiple cases to work on, and are often too busy to be interviewed by students people working in automated vehicle departments are investigated.

In automotive companies the best representatives probably would be innovation managers or team leaders of the automation department. Some of these filled in the questionnaire. However, most surveys are filled in by developers. These have more time, are easier to contact, but probably have

less link to the corporate mission. The same holds for governmental institutions. However, as most people here make policies and should have a strong link with the institutional mission this is probably less of an issue.

To conclude, the chosen representatives give a good indication but the in further research managers of departments are probably more suitable as participants for this kind of research.

The method in relation to Value Sensitive Design
The performed method is based upon Value Sensitive Design (VSD) literature (Flanagan et al. 2008; Friedman et al. 2013). VSD explains three investigations: empirical, technical and conceptual. In this research the focus is on the empirical investigation. Downside of only using one type of investigation becomes clear in the research. For instance, the aspect of "security" was not mentioned in the interviews and had to be added from literature. Which is a conceptual inquiry.

A second difference in relation to other VSD research is that in this research the actors groups are treated like groups over the whole scope of the research. In other VSD research many actors are investigated to make the value clusters, but then the relative importance of the values is set by the researchers. Whereas in this research first value profiles are made in a questionnaire and then the actors together indicate the importance of the values. Separating the actors gives more insight in the tensions between the actors and gives more power to the actors, as they make the final value profile themselves. By investing separate actors groups the tensions between actors become more clear and especially more explicit.

Future research with this method
The method shows interesting results, but still improvements can be made if the method is performed a next time. First of all, the sample of the method is lacking. The questionnaire has a biased and small group, in a next study this should be much wider. Many VSD studies highlight that diversity in the respondent group is of importance (Cuppen 2012; Flanagan et al. 2008). What holds for the questionnaire also holds for the workshops. Here students and graduates played the roles. This shows that the method works, but the outcomes are not valid for use. For a next time more workshops are needed, especially as the standard deviation is rather high. Besides that, all values need to be specified, where now only 4 are done.

In the workshops and some reactions in the questionnaire made clear that the values are too vague to be scored well. Especially when people need to discuss the definitions need to be clear and have no double interpretation. Especially the value of *self-determination* could have better been split up in autonomy and privacy. This shows that the specification step is also of interest when interpreting the results of the questionnaire.

For the whole method holds that the main focus was on empirical investigations, whereas more conceptual and technical investigations (Friedman 2015) could lead to more insights.

Scalability of the process
The proposed method is performed on small scale. However, the method is intended to be performed with more people. However, how scalable is this method and how would it look like for manufacturers or governments who like to use it?

This example is written from the viewpoint of a car manufacturer, of course also a governmental institution could use the method as a basis for policy design. First the car manufacturer should admit to itself that this method is meant to make a new design for the car together with the public. Important to see is that the method is not intended to convince others to be in favour of his case. The car manufacturers should interview different people about their values, or do more technical and conceptual research. The values from this research can be used, but if the manufacturers themselves do interviews they get more feeling with the values. A critical aspect for the manufacturer is not to frame the values in his perspective but to be neutral. Next, a questionnaire has to be send to a large number of future consumers, but also to non-consumers. Also the government can be asked to fill in the questionnaire. Next step is to organise workshops. Multiple workshops have to be set-up with a members of the public with different backgrounds. It is better if the employees participating in the workshops are not the same as the ones setting up the workshops. In this way they are not biased or have more information than the other participants.

The method in other areas
The proposed method can be used on wider topics than only automated vehicles. This could even be more interesting. Where most people have a positive association with automated vehicles, this might not be the case with other innovations. It is also quite easy to imagine automated vehicles, where the effects of Nano-technology are harder to picture. The same set-up as is used for automated vehicles can be used for other technologies. This method, were the public is involved closely, becomes more and more interesting as technologies come closer to us. As technology gets closer, emotions get more important, which are hard to grasp for experts (Roeser 2012). These emotions can be taken into account in this method.

A complicating factor which almost only arises for automated vehicles is that the public consists of two groups: consumers and non-consumers. For most controversial technologies the innovation only influence the consumer (smart energy meter) or the whole society equal (genetically modified foods). This makes automated vehicles an interesting topic to research.

Embedding of this method in formal design or policy making process
Besides if the outcomes can lead to a design the method should also be formally embedded in a policymaking or design structure. At this moment the method is performed by an in-dependent researcher, without a client. Still, impact is only achieved if the outcomes are used. This embedding is out of scope of this research, but still briefly discussed here.

Three ways of using the method
The outcomes of the method are meant for governments to base policies on, or for manufacturers to base design in. There are three ways by which the method can be used. First, only the outcomes of the method can be used. This means that a government or manufacturer reads the of a research and bases his design upon the outcomes. This is the least favourable way, as in this way no interaction is there between the designer and the public itself. Therefore there is no real inclusion and reflexivity (Stilgoe et al. 2013).

Second, the method can be performed by the institution itself. They then facilitate the dialogue and use the outcomes. In this way they can change their design iteratively with the public. Also the

workshops become more interesting as their values are negotiated and not the values of another car manufacturer.

A slightly different option is the third option, where an in-dependent party facilitates the dialogue on behalf of a manufacturer or government. In this way the neutrality of the facilitator is stronger embedded.

Incentives for a government or manufacturer to use the method
This research focusses on the method itself, the implementation is out of scope, but still important to discuss briefly. Governments or manufacturers should have an incentive to make use of the method, or more important, to incorporate values of the public in their designs.

Governments are already quite familiar with participation of the public in decision making. On many topics in the Netherlands is some kind of participation. The EU is a strong leader in the RRI field (European Commission 2013) and aims to implement RRI principles.

Car manufacturers often operate in secrecy and develop products preferably on their own (Aerts 2015, chap.2). Still, the method, but also other public participation has shown also result as tool to develop new ideas (Sutcliffe 2011). However, the use of these methods still is not clear for many innovators. To move the car industry stronger incentives are needed. A strong voice from the public or the government is possibly the only incentive that will work to make sure the public is involved more. Difficulty is that the automotive industry operates internationally. Therefore the American government, the EU, but also the FIA World Council for Mobility and Automobile (the international ANWB), could use their influence or policies to guarantee that no fundamental ethical principles are harmed.

13.2. Does the method meet the 'other criteria' set for a constructive dialogue

In chapter 10.4 four aspects are mentioned which the method should have. Besides constructive and a dialogue the method should also be: 1) usable with multiple actors, 2) have freedom for designers, 3) overcome the problem that there is no clear image of self-driving cars and overcomes that 4) there is no common language between experts and the public.

Involvement of multiple actors
First, the inclusion of multiple actors. In VSD it is common to have one expert group, and one laymen group and in software (for example Meijdam 2015; Friedman et al. 2002 or examples in Flanagan et al. 2008 and Friedman & Kahn 2002). There are however studies done with multiple groups (like UrbanSim explained by Friedman et al. 2013), but they a minority. The method developed for this research makes use of these multiple groups and makes a value profile per actor group by means of the questionnaire.

Freedom for designers
The second aspect is that input of the public often leads to incremental changes instead of radical changes (Henry Ford: "if I had listened to my customers I would have given them a faster horse!"). This criticism is hard to test as no final design is made. However, the input for designers are the norms, which probably lead to enough freedom. To speak in terms of Fords famous quote: if Ford

would have researched values he probably would have found that the customers would like to improve the speed of their transportation. Values can be used to broaden the scope instead of narrowing it down. Besides that it can be seen that in the workshop also new ideas arise, which are never expressed in media or literature.

No clear image of future self-driving cars
The third aspect is that there is no common view (no kollektive Vorstellungsbasis as Fraedrich & Lenz (2014) explain) Due to a more utopian approach (asking, 'how does your ideal self-driving car look like) a common view is not important. The participants first form their own views and then negotiate a collective view in the workshop. The only thing explained in the workshops is level 3 automation, this is done in a few sentences and only to narrow down the discussion. So, the method overcomes the lack of a common view.

No common language between experts and public
The last aspect is the lack of a common language between experts (who are used to talking in ratio) and the public (who mostly use emotion). Values form the common language in this research. As values are easy to grasp they work for both the experts and non-experts. Nevertheless, the values are too vague for a real detailed discussion. Therefore the specification to norms is important, which happens in the workshop. In future research this aspect should be emphasised.

13.3. Social desirability of the two development paths

One of the aspects the method intents, is to research the social desirability of different development paths. The research investigates two paths for self-driving cars: cooperative driving, or autonomous driving. The two are summarised in figure 13-2.

The 2 development paths: cooperative & autonomous
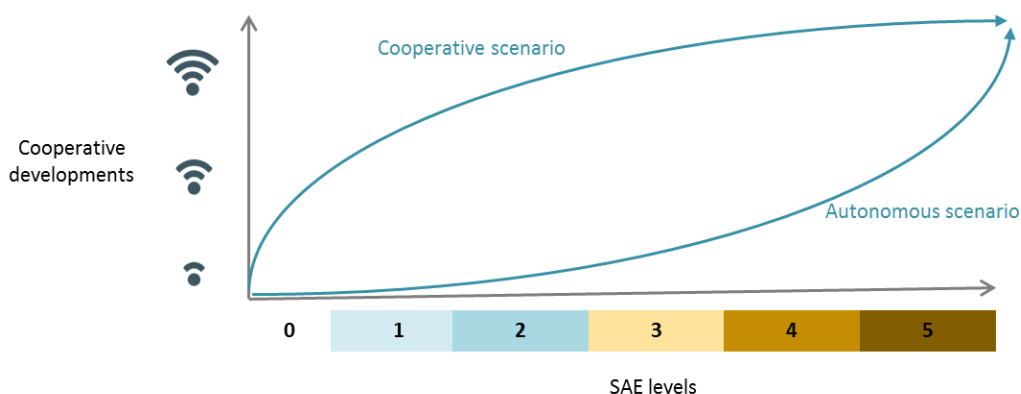
figure 13-2: the two development paths researched in this thesis. Autonomous driving first aims to develop a car which drives on its own. The cooperative path directly adds communication to the vehicle.

A value profile for the two development paths
The best comparison could be made if the two scenarios have had their own value profile. However, making this profile is hard to quantify. Therefore, a schematic figure is made based upon literature. The result can be seen in figure 13-3.

The main difference for the two development paths is that autonomous vehicles only look to the outside and cooperative vehicles also communicate with other vehicles and infrastructure. Where cooperative vehicles can "listen and talk", autonomous vehicles can be called "deaf-mute" (Shladover 2015, p.24). Direct effect of this is that cooperative cars can drive closer to each other and that the *traffic flow* is optimised (Shladover 2015; Timmer & Kool 2014). This is also concluded from the simulations done in part A of this research (see in the experiments in chapter 7 or the conclusions in chapter 9.1).

Due connection the *safety* is also higher according to Shladover (2015, p.26). If cars drive cooperative they can pass on information about the road condition or anticipate on breaking vehicles downstream. Other sources however explain that a closed system will lead to more safety (Timmer & Kool 2014, p.75). However, what they mean is called security in this research. Therefore safety will be slightly in favour of cooperative driving.

As Timmer and Kool (2014, p.75) and others (Alkim & Veenis 2015, p.32) already mention, is *security* in favour of the autonomous scenario. Without a connection hacking gets harder. Still, is hacking possible as also autonomous vehicles will probably have a connection with the internet to update. The Tesla model S (not cooperative) and a Jeep Cherokee (not even automated) are both hacked recently (NOS 2015). Therefore, the slider is not totally in favour of the autonomous scenario.

Also *self-determination* is higher for the autonomous scenario. In both scenarios restrictions can be added which could harm the drivers autonomy. However, in the cooperative scenario this could also be done online. The chance of a privacy harm is also lower in the autonomous scenario, as there are less connections (Alkim & Veenis 2015, p.32). However, this does not have to mean that it actually is lower, only that the chance is lower.

Lastly, there are several values who do not differ per development path. These are the *time spend differently*, *liability*, *accessible for everyone* and *equality*. The *liability* and *equality* have to do with the context of the innovation and the other two do not differ for the two paths. The other two are not different in both scenarios.

Difference in value profile per development path
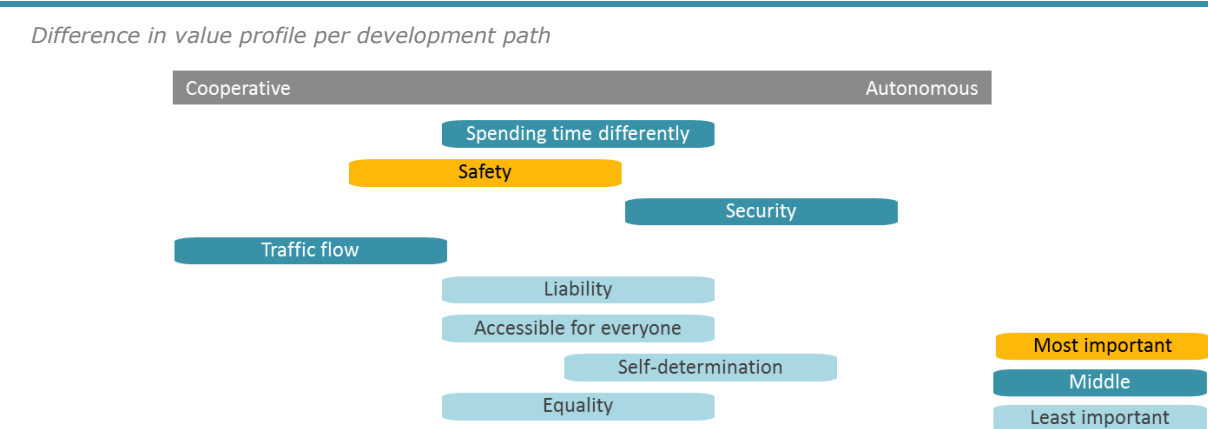
figure 13-3: The colours indicate the importance of the values according to all stakeholders. The place of the bars shows in which scenario they are more satisfied.

Comparing the value profile to the actors
What can be seen is that both scenarios have their advantages and disadvantages in relation to the values. In the cooperative path more attention has to be payed to the self-determination and security and in the cooperative path to traffic flow and safety.

For the car manufacturer the autonomous path seems favourable. They value *security* and *self-determination* more than the *traffic flow*. Aerts (2015, chap.2) and Timmer & Kool (2014, pp.52 & 75) [42]also see the autonomous path more benefits for the car manufacturer. The consumer is less in favour of the autonomous scenario as he also values traffic flow. The consumers are in the middle of the two scenarios.

The government and the non-user value *safety* and *traffic flow* more than *security* and *self-determination*. This is logical as these are more system benefits whereas especially *self-determination* is a personal benefit. This is also often mentioned in literature (Timmer & Kool 2014; Aerts 2015).

Innovation of large car manufacturers and newcomers mainly focus on autonomous driving (see Google car, Tesla, Volvo) (Shladover 2015; Aerts 2015; Timmer & Kool 2014) and public parties as universities or governmental initiatives focus on cooperative driving (DAVI, GCDC). Nevertheless, also universities research on automation and many manufacturers have department researching cooperative driving.

Preference per development path per actor
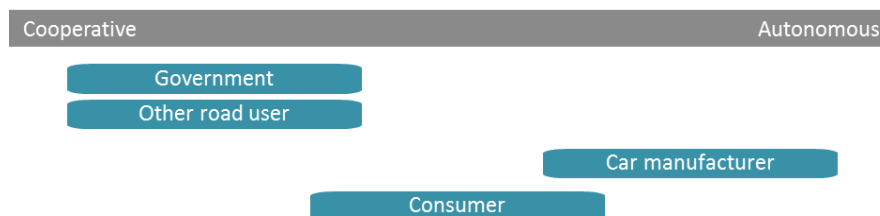
figure 13-4: The positions of the three actors on the scale from cooperative to autonomous.

The paths compared to Responsible Research and Innovation (RRI) literature
In chapter 1.4 *The* innovation in the light of Responsible Innovation (RI) already 5 points of criticism are raised. Most of the points hold for both scenarios. However, the inclusion of stakeholders is somewhat better for the cooperative part. Here you inherently need multiple parties, but still the public is missing. In his literature review Aerts (2015, chap.2) explains that "[w]hereas the cooperative driving trajectory is coordinated via public-private collaborations on multiple levels, the autonomous driving trajectory is mainly coordinated in-house implying that there is a lot of secrecy." He explains the cooperative driving therefore is more based on 'consensus'. Whereas the

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[42] Timmer & Kool (2014, p52): "Zo zijn er verschillende bedrijfsmatige motieven om de zelfsturende auto op autonome in plaats van coöperatieve grondslag te ontwikkelen, en het product af te schermen van het netwerk van technologieën", which means: "there are different business motives to develop autonomous vehicles in stead of cooperative, for instance to fence the technology off from a network of technologies."

autonomous path is more based upon 'competition'. However, this 'consensus' still is between a smaller group than is advocated by RRI literature and in this report in chapter 1.4

FINDINGS BASED UPON COMPARISON TO THE PATHS
The cooperative path seems to the path preferred by the non-consumer and the government, the consumer is in the middle and the autonomous path is the preferred path of the manufacturer. Two aspects are striking.

First of all, it can be seen that in none of these scenarios are without moral downsides. That means that none of the two practical scenarios match the utopian views of the value profiles. This can be called "moral overload" (Van den Hoven et al. 2012). This means that morally you want have more than practically is available. To overcome a dilemma of moral overload you can of course decrease your expectations, or innovate (Van den Hoven et al. 2012; Van de Poel 2015). Innovating is the most favourable option.

Secondly, the manufacturers, the ones with the actual R&D capacity, have another view than the other three actors. The manufacturers are the ones making decisions, the public and government can steer a little, but mainly can say 'yes' or 'no' to an product. This means that involving the public is crucial for them to ensure that their values are taken into account in the final product. Governments or interest groups can play an essential role in this, as the public itself probably does not see this problem.

13.4. The responsible future of automated vehicles

In chapter 1.4 is explained that the automated vehicle innovation is no responsible innovation and shows signs of an irresponsible innovation. This method is set-up to help the automated vehicle innovation become more responsible. But, if this method is practiced, on what aspects would it help.

The methods could improve responsibility of the innovation on many aspects
What becomes clear from this research is that there is not only a need to involve the public in literature (as chapter 1.4 shows), but also in practice, as the questionnaire shows different value profiles. Especially aspects as *traffic flow* (and linked CO2 emissions) and *self-determination* (privacy and autonomy) are shown to be discussion points.

Following the four points Stilgoe et al.(2013) define for an Responsible Innovation, especially the *inclusion* and *responsiveness* are strengthened by the method. The *reflexivity* is improved a little, but this is mainly an internal affair. The *anticipation* on possible effects has to be done with Technology Assessments. However, the outcomes can be related to the value profiles of the actors. So, the method helps on many aspects, but is not the only thing needed to become a Responsible Innovation.

The method does not capture all aspects of RRI
Besides that, the method finds "intended values" (van de Poel & Kroes 2014, p.120). Hereafter two steps happen which can blur the values in the actual product: the design and the use of the product. This means that in the design the "intended values" will become "embodied values". Which can be different. In the use phase the values become the "realised values". However, to match the realised

with the intended values is a research on its own. Thus, the used method mainly focusses on upstream engagement (intended values), where still midstream and downstream engagement needs to be assured. This is important, but outside the scope of this research.

Therefore, the proposed method probably helps the automated vehicle innovation to become more responsible. However, it will not make the total innovation at once responsible. It is a good starting point, which will ensure no fundamental ethical principles are neglected and stakeholders are included. However, still many other aspects need to be improved. This method does not change anything to a framed public debate or to improve transparency. Besides that, these activities do not inherently will lead to better or more profitable innovations, but it will certainly help to have an ethical ground for decisions.

14 Conclusions

Automated vehicles will soon be part of our society, however, in what form is still unclear (cooperative or autonomous, with what business model). The impacts that automated vehicles have on society are expected to be wide (mobility, social, economic). These effects are wider than just the consumers of automated vehicles and also affect non-users. In the current innovation the public (users and non-users) do not have a voice(Timmer & Kool 2014). Therefore, a constructive dialogue between the future consumers, the other road users, the government and manufacturers is needed.

In this research a constructive dialogue method is developed. The basis for this are the so called 'empirical investigations' from Value Sensitive Design literature, enriched with insights from other methods. Via interviews the values of the actors are researched and ranked on importance via a questionnaire. These show insight in the value profiles per actor group. In the second phase is, in a workshop, tried to construct one common value profile. Besides that are the values specified to norms. This workshop shows where the tensions between the values are. The method is tested on small scale and the final workshops are performed with students instead of the real actors. Therefore the outcomes are not valid to draw conclusions upon, although, the atmosphere of the workshops is of interest.

14.1. Answers to the sub-questions

The sub-questions will be answered in the same order as presented in the introduction.

1) Which criteria from literature should the method meet to be a constructive dialogue?
The method should meet criteria three types of criteria to be called a constructive dialogue. The method should be 'constructive', it should be a 'dialogue' and it should overcome the 'innovation specific criteria'. All three criteria are summarised in table 14-1. In the table is also shown where the criteria originate from.

table 14-1: Overview of all criteria the constructive dialogue for automated vehicles should meet.

Aspect	Criteria	Originates from
Constructive	Aimed at influencing technological choice and design processes	Constructive Technology Assessment (Schot & Rip 1997)
Dialogue	1. Equality 2. Mutual trust and respect 3. Openness 4. Argumentative quality 5. Reflective nature	Definitions of Smaling (2008)
Innovation specific	1. Multiple actors 2. Freedom for designers 3. Overcome that there is no clear image of the self-driving cars 4. Overcome that there is no common language experts and public	Explained in chapter 10. Sources for the last two are Fraedrich & Lenz (2014) and Roeser (2012)

The first two criteria can be used for every constructive dialogue, the third are specific for automated vehicles. Still, those criteria can also be relevant for some innovations, they won't be for all and therefore cannot be generalised.

2) What values, of the relevant actors, are at play in the development of automated vehicles?

The four relevant actors in this research are the future users of automated vehicles, the other road users (which together form the public), the government and the car manufacturers. From the five interviews, literature and the cluster session with experts 8 values are derived. These are: *spending time differently, safety, higher traffic flow, liability, accessible for everyone, self-determination, equality* and *security*. All named values here can be found in other literature, the addition of this research is that is tried to made a collectively exhaustive list.

These values can be of input for both designs of automated vehicles and policies. To do so, two aspects are needed. First of all, the relative importance of the values are needed. Second, the values need to be specified to norms.

3) What is the relative importance of the identified values per actor?

Via a questionnaire the relative importance of the values per actor is determined. In total 144 respondents filled in the questionnaire, mainly consumers and non-consumers. In figure 14-1 the values are ranked on importance per actor.

Relative importance of the values

	Consumer n=58	Non-consumer (n=70)	Government (n=9)	Car manufacturers (n=7)
important	Safety (1.9)	Safety (1.5)	Safety (1.2)	Spending time differently (2.7)
	Traffic flow (2.6)	Traffic flow (2.8)	Spending time differently (3.3)	Safety (2.8)
	Security (3.3)	Security (3.2)	Traffic flow (3.4)	Security (3.0)
	Spending time differently (3.8)	Self-determination (4.4)	Security (3.6)	Self-determination (3.7)
	Liability (4.6)	Accessible for everyone (4.6)	Liability (5.1)	Accessible for everyone (3.8)
	Self-determination (4.9)	Liability (4.9)	Accessible for everyone (5.3)	Liability (4.2)
	Accessible for everyone (5.0)	Equality (4.9)	Equality (5.6)	Traffic flow (4.7)
	Equality (5.6)	Spending time differently (5.6)	Self-determination (6.0)	Equality (6.3)
unimportant				

Relative importance (vertical axis label)

figure 14-1: Relative importance of the values per actor group. The same values have the same colours. The number behind the value name is the average rank per group. The amount of respondents per group are shown after the actor names.

From the ranking shown in figure 14-1 some conclusions can be drawn:

Safety is the most important value, except for the manufacturers who value safety the less
From figure 14-1 it can be seen that all parties agree that *safety* is the most important value for future automated vehicles. Except for the car manufacturers, the ones who actually design the vehicles, value the safety less than the others do. However, it should be noted that the sample size is low (n=7) and the standard deviation is high (2.2 on the 7 respondents, on this value this is on average 1.0 for all parties). This probably means that a small share of the respondents do not value safety as much as the others do. This indicates that some car manufacturers value *safety* less, however, the sample is too small to draw firm conclusions.

Few discussions on security, accessibility for everyone, liability and equality
There are four values on which almost no difference in ranking is. These are *security, accessibility for everyone, liability and equality*. *Security* is scored by every party around the 3rd rank. *Accessibility for everyone* and *liability* aspects are found mildly important. Car manufacturers score on both aspects somewhat higher, but there is no large difference. *Equality* is found unimportant by all parties. This means that there does not have to be equality in investments by the government, as everyone agrees that subsidies for self-driving cars are fine. Furthermore, the government and ANWB added to this point that this should only be the case if automated vehicles have societal benefits.

Differences in importance of the values for traffic flow, self-determination and spending time differently
On three values there is a disagreement: *traffic flow*, *self-determination* and *spending time differently*.

- *Traffic flow* is valued by everyone, except for the car manufacturers. This might be problematic as they are the ones developing the vehicles. Here the government or interest parties (such as the ANWB or FIA) should play a role to ensure the embedding of this value. Part A of this research shows that a slightly lower traffic flow efficiency can lead to much more congestion (more in chapter 15).
- *Self-determination* is found important by the manufacturers and the consumers, whereas the government and the non-users do not value this. This can lead to tensions if the government wants to set constrains to the freedom of the driver.
- The last one, *spending time differently*, is not valued by the non-consumer, but the other three value it. This point will probably not lead to value tensions as in interviews and the questionnaire the non-consumers indicate that they do not find this an important aspect as they themselves have no advantage and not because they are against this aspect. However, some non-consumers state to preferably not see someone drive while doing something else. If that is the case, this alienated or unsafe feeling is a point of attention.

4) To what extent can one common value profile be created in a constructive dialogue?
During the research more and more the tensions between actors and values become clear. In the interviews almost all actors named the same values (safety, traffic flow and spending time differently). The questionnaire showed that there are differences in importance. In the test workshop and the two following workshops a common value profile was negotiated. During the test workshop and the first workshop the participants created a common value profile, on which they all agreed. In

the second workshop it took longer to create a common value profile. Here many discussions were on the interpretation of different values. Therefore, in that session more attention is given to the specification. So, dividing points can lead to a common value profile, but is no guarantee for an outcome. However, as the tensions are already an insight it this still is valuable input.

In this research the workshops are done with students, it should still be tested if the real actors can come to consensus. Still, the indications are hopeful.

That it is difficult to come to a single common value profile does not indicate that the automated vehicle innovation is in a gridlock, as value tensions also arise in the current world. It would be more problematic if two actors have opposite opinions. In the workshops only differences in importance were seen. This means that the innovation is in a case of moral overload (Van den Hoven et al. 2012). This means the innovation should meet more criteria that currently can be met. Van den Hoven, but also Van de Poel (2015) explains that 'innovation' is a way to overcome a moral overload. That at this moment the innovation does mean that we need to innovate to meet for instance both safety and traffic flow criteria.

5) Which value tensions become clear when the values are specified to design input?
This question is difficult to answer as the workshops were done with students and not with the real actors. The workshops revealed though that they are a way to make the tensions clear in this setting. Not only the tensions in value (I find this important), but also the tension in interpretation (for me this aspects means) become clear. Accordingly, it can be seen that what Van de Poel (2013, p.265) explains in his paper can be underpinned with empirical evidence in this study. He explains specifying "…. helps to trace more precisely the value judgments and possible disagreements".

The tensions during the workshop let to multiple discussions. Most discussion were about *spending time differently, traffic flow* and *self-determination*. In most cases there is a struggle between the manufacturer and user on one side and the non-user and government on the other. Sometimes also the public thinks different than the government and the manufacturer, for instance in a privacy debate. In contrast with the questionnaire, there is almost no discussion about safety (the third largest difference in scores).

This means that the method is suitable for the use in the future workshops and provides sufficient insights in values and tensions between actors.

14.2. Answer on the main question

The main question of this research is: *to what extent can a constructive dialogue method be developed to give input for future designs of automated vehicles?* For this research a constructive dialogue method is developed and performed. Because the workshops are not done with the real method the method cannot be tested, however, indications to what extend is succeeded to develop a constructive dialogue can be given.

The actual dialogue took place in the workshops, but all the steps before the workshops were needed to give input to the workshops. For the method three types of criteria are set: it should be

'constructive', it should be a 'dialogue' and it should meet the 'other criteria'. These are discussed here below

There are indications that the method is constructive
Criterion for being 'constructive' is that it is "aimed at influencing technological choice and design processes". The set-up of the method is aimed to be constructive. Throughout the whole method, input is given for new designs of future automated vehicles. This starts in the interviews (by designing the ideal self-driving car) and continues to the workshops where specific decisions are discussed. Besides the set-up it can be seen that in the workshop ideas are translated from rather vague values to more concrete end-norms. In the workshop also new ideas arise for the future automated vehicles.

There are indications that the method is a dialogue
Besides constructive, the method should also be a dialogue. Smaling (2008) defines five criteria : equality, mutual trust and respect, openness, argumentative quality and a reflective nature. The five will be discussed in this paragraph. It can be seen that the participants are *equal* in the method and there is mutual *respect* and *trust* (or at least there are no indications for distrust or disrespect). Most positive is the openness of people, in the first step of the workshop the students indicate their intentions and in the second they even help each other with finding arguments. Further investigations are needed to see if this is also the case with real actors. The *argumentative quality* is fine as well. The fifth criterion, the *reflective nature*, is impossible to test as students are used.

The method meets the innovation specific criteria
The last criterion, is that it should meet the 'innovation specific criteria'. Four of them are set, and all are met. First, the method includes all *four actors* in the value sensitive design method. Secondly, the use of values and norms still give *freedom for the designer* to give their own interpretation. Manufacturers still need to specify these norms to design requirements. A norm of for instance 10% less accidents can still lead to multiple solutions. Thirdly, the method overcomes the problem that *there is no clear image of self-driving cars* by the public. By asking for input, instead of reflecting upon the technology, the image people have is not important. The method is more utopian than reflective and provides input instead of reflecting, which is needed in this phase of the developments. The fourth aspect is that a common language needs to be found for experts and the public. This is found in the values. These values are still vague. This makes the discussion broad instead on a specific feature or technology.

The method gives empirical evidence for Van de Poels set-up and new ideas arise
Besides these three aspects which make the method a constructive dialogue for automated vehicles, more positive aspects arise. New ideas arise in the workshop and the workshop shows practical relevance for the manufacturers. Also what Van de Poel (2013) already described in his paper happens: value disagreements are traced and possible disagreements come to the surface. Next to this, it can be seen that on many aspects consensus is found on the disagreements.

The method still has to be embedded formally to guarantee impact
Still, the embedding of the method in a business or policy making form has to be investigated. At this moment the method properly works, but it can only have an effect if the outcomes are used. This is out of scope for this research, but it has to be done to guarantee impact.

SYNTHESIS

Although a part of the method is performed with students, instead of the real actors, the method gives clear indications that meets the criteria to be called a constructive dialogue. So, a constructive dialogue method is developed in this research.

14.3. Outlook to literature and practice

This research adds on a few points to practice and literature. Both are explained in this section.

Practice: a more responsible innovation

There is a need for a dialogue between the public, government and car manufacturers

Just as literature (Timmer & Kool 2014; Pel et al. 2014; UBC 2015; Halll 2015) already explained, I want to stress again that it is of importance for all actors to involve the public in the automated vehicle innovation. The automated vehicles will have mayor impacts on the public, therefore their opinions should be heard. Andersen & Jæger (1999, p.334) explain this very clear *"… why should ordinary citizens, without any specific knowledge about the technology in question, be asked to advise politicians and society in general on such difficult and intricate matters? One simple answer is, because of democracy."*

In addition to their work this thesis demonstrates that the automated vehicle innovation shows signs of an irresponsible innovation and certainly cannot be called a responsible innovation. The results of a survey with a small sample (n=144) add to this that the value profiles of the car manufacturers differ from the other researched groups. Just as literature indicates, from the survey it can be concluded that the manufacturers prefer another development path than the other actor groups. The non-inclusion of the public, the signs of an irresponsible innovation and the different visions highlight the need for a dialogue.

Besides the involvement of the public, also the way they are involved is also important. Asking the question: "do you *want / see the advantage of / like* automated vehicles?" will not give an interesting answer as every consumer has a his own picture of automated vehicles in mind (Fraedrich & Lenz 2014). Asking utopian questions like: "what does your ideal automated vehicle look like?" or "what do you find important for future self-driving cars?" gives constructive input for design.

This method can be one of the steps towards a more responsible innovation

Although the workshops are tested on students, the research indicates that the method can be used to contribute to a more responsible nature of the automated vehicle innovation. Especially the inclusion and the responsiveness of the innovation will improve with the use of this method. Still, this method will not make the total innovation responsible. This method does not change anything to a framed public debate or to improve transparency. The essay in chapter 15 will discuss all five aspects of the innovation. Besides these, are the outcome of the workshops "intended values" or "intended norms". The design and use of automated vehicles can blur these intended values to "realised values". To avoid adverse outcomes also midstream and downstream methods need to be used.

Literature

The implications for literature are split up in a few themes.

The use of quantitative value profiles in Value Sensitive Design
The most important point is that in a Value Sensitive Design the use of quantitative value profiles per actor are insightful. Especially if in other research multiple actors are investigated and the researchers want to create one common value profile. This research first investigates the value profiles of different actors via a questionnaire and lets the actors themselves form a common value profile. By doing this, the value profiles of the different actors can be compared and disagreements can be traced. In other investigations, for instance Michalopoulos et al. (2013), a quantitative value profile was made, but then only for one actor group. This research shows that the quantitative profiles are insightful and can be used to see where tensions are between groups.

The specifying method of Van de Poel works with multiple actors
The workshops of this research also shows that the elements of the method Van de Poel (2013) explains in his paper *translating values to design requirements* work. In this research only the specifying step from values to norms is investigated. Van de Poel (2013, p.265) explains that it "helps to trace more precisely the value judgments and possible disagreements about them, even it does not offer a way to solve these conflicts". It indeed helps to trace disagreements and value judgements. Moreover, it does help to solve value conflicts. In the workshop the students come to agreements about values their collective ideal automated vehicle should embrace. In other research (for instance Meijdam 2015) only one single group of actors specifies the values to norms, whereas in this research multiple actors together do this specification.

Finding values by letting participants design flyers
From the interviews it can be concluded that the creative element in interviews works. After a few questions the participant was asked to design the flyer of his ideal automated vehicle. This method is based upon Osterwalder (2014). Besides laddering (the traditional technique of asking "why" used in Meijdam 2015, or Oppenhuisen & Sikkel 2000 and argued by Friedman et al. 2013), also this method works to find values. A positive point of the flyer is that it feels less intrusive and this way the values become explicit. It is believed that the methods can be combined.

14.4. Future work

To improve this method
The current method can be improved in multiple ways. First, the questionnaires were done among a small and biased group and the workshops with students and graduates instead of the real actors. The group of actors can also be extended or diversified. In addition, interest groups, insurance companies or more diverse members of the public can be asked for input. In each workshop only 3 values are specified to norms to safe time. The other values should also be specified to see if there are any problems there and if in that case a multi-issue game can arise.

Not only the workshops and the questionnaires can be improved, also the investigation to the values at play can be improved. In this research the focus was on the empirical analysis and overshadowed the conceptual and technical analysis. It is believed that those two investigations can bring extra insights.

The method is meant to give input to design and policy making, however, it is not tested if the outcomes will lead to good products or policies. This should investigated in further research.

Formal embedding of the method
Goal of this method is that it is used for policy making or future designs of automated vehicles. Of course the outcomes of this research, of the ones of a next can be used by a manufacturer or government. However, way better for them to do is to perform the method themselves. In this way they get a feeling with the values.

Difficult point in this is why the manufacturers would start a method like this. As Aerts (2015) explains is the autonomous development path characterised by secrecy. To open the shell of un-inclusion and secrecy many efforts are needed. In the discussion some examples are given. They all come done on a strong voice of a third party is needed. This can be the government, or a mix of interest groups and the public. How exactly this should be done is out of scope of this research, but of importance for the success of this or similar methods to include the public.

Integration

15 Integration of both studies

Both studies investigate the same topic: automated vehicles. Or, to be more specific: the differences in the impacts of two development paths for the large scale introduction of automated vehicles. Where the transportation part (A) researches the mobility effects (which is already a broad topic), part B researches a wider range of effects. The communication part researches how mobility, safety, self-determination and other values at play.

The results of the transportation part give the ability to make a cost-benefit analysis to the different development paths . This mathematical and monetary way of researching is strongly utilitarian (van de Poel & Royakkers 2011).

The communication part contradicts with the view of transportation part. Not the largest happiness or largest welfare for the most people is of interest, but if there are no ethical principles harmed. This research is more deontological. This does not mean that not the greatest happiness is of interest, but that "[.....], according to Kant, happiness is only conditionally good; it is only good insofar as brought about by the good will, i.e. out of respect for the moral law" (van de Poel & Kroes 2014, p.106). This "respect for the moral law" is researched in the communication part.

These two different approaches make integration of a thesis hard. Still, investigating both views make the sum of the two researches stronger than the two individual, as a more wide scope is present.

15.1. Links between the two studies

The two studies have a same starting point: assessing the effects of different development paths for automated vehicles, but differ in approach and scope. However, there are a few links.

The low priority of traffic flow of manufacturers can have large effects
The first one is between the traffic flow efficiency and the PCU value. If manufacturers, the ones responsible for the product, value traffic flow high (or take values of others into account) the PCU value in the transportation research is likely to decrease. However, as manufacturers do not value traffic flow at all, this value will increase. Simulations show that a small increase in PCU value can lead to a large increase in loss hours. The priorities of the car manufacturers can therefore lead much more congestion. We might therefore end up in the lower boundaries of the simulations performed in the transportation part.

To prevent this from happening regulation or other restricting policies are needed. In the transportation part this is already advised, but the conclusions from the communication part strengthen this advice.

Value of time and spending time different
The *value of time* (TP) is linked to the value of *spending time differently* (communication)*.* If consumers value this aspect more the value of time probably decreases. Consumers value this aspect, but find others more important (safety, security and traffic flow). Therefore, no striking conclusions can be drawn on this aspect.

The two development paths
Both researches investigate the two development paths for automated driving. What can be concluded from the transportation part is that the cooperative path has more benefits for mobility. The autonomous path provides benefits for the user (in terms of value of time and less fuel costs), but has negative effects on mobility. It can be seen that the government and non-user value the cooperative driving path. This is logical as they are the other road user and the one caring for society in general. As the car manufacturers are more interested in the autonomous path the mobility aspect can become a point of discussion.

15.2. Essay integration

The essay with the integration of both topics can be seen in appendix R. This is done as the essay has its own literature list and then can be used and read as separate article.

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Appendices

Table of contents for the appendices:

Appendix A: Processing of OViN and MON data

The OViN and OVG[43] are used to generate a base year and to calibrate the time of day choice and mode choice. For the five modes (car, passenger, train, BTM, slow) the travel times, distances and average amount of trips per day for each of the 42 relations is needed.

First is described how the municipalities are grouped into the 6 zones, than the modes are shortly discussed. Finally some remarks are given on trips outside the Netherlands or on missing data entries. The appendix concludes with a comparison with the Scenario Explorer data.

For the whole research data from 5 years are used:
- 2010 – 2013 to calibrate the time of day choice and mode choice
- 2010 – 2013 are aggregated to construct a base year
- 1990 to compare with the ScenarioExplorer base year

List of municipalities to zones

All municipalities are grouped into six zones. The same zones are used as in the ScenarioExplorer (1999d). As the ScenarioExplorer literature is incomplete about their definitions for the municipalities, new groups are made. The Randstad is defined according to the CBS (2015b) website: the whole of South Holland, Utrecht (excluded the south eastern part), North Holland (excluded Alkmaar and the north) and Almere.

The definitions of all zones are:

LCR	Large cities in the Randstad	Amsterdam, Utrecht, Rotterdam, The Hague
ST-LCR	Satellite towns of large cities in the Randstad	Cities bordering the large cities (e.g. Rijswijk, Amstelveen). Except for rural municipalities consisting of multiple smaller villages (e.g. Westland, Waterland)
CR	Other large cities in the Randstad	Municipalities larger than 100.000 (e.g. Dordrecht) or defined as cities by the CBS (e.g. Zoetermeer) inhabitants in the Randstad
RR	Rest of the Randstad	The remainder of the Randstad (e.g. Lisse, Baarn)
CRN	Cities in the rest of the Netherlands	Municipalities larger than 100.000 inhabitants (e.g. Groningen) or defined as cities by the CBS outside the Randstad (e.g. Venlo)
RN	Rest Netherlands	The rest of the Netherlands

As municipality borders differ per year the definitions of 2015 are used. These definitions are used for 1999 and 2010-2013. An overview of all municipalities per zone can be found in the appendix B.

From 22 OViN modes to 5 modes

OViN investigates 22 modes. In this research these are grouped to 5 modes. For all multimodal trips the main mode is taken as mode, the travel time and distance are the sum of all separate trips.

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[43] OViN (Onderzoek Verplaatsing in Nederland, 2010 till now) and OVG (Onderzoeksverplaatsingsgedrag, 1985-2003) are succeeding surveys to the travel behaviour in the Netherlands done by the central bureau of statistics and Rijkswaterstaat (Cbs 2011).

Mode this research	Mode in OViN
Train	Train
Passenger	Car passenger
Car	Car, Van, Camper, Motor, Taxi
Slow	Bike, Moped, Bike passenger, skates, by feet, disabled transport, pram
BTM	Bus, Tram, Metro, Touring Cars

Some other modes are left out of the model, as they are too small in number or do not contribute to the intensity on the road. These are trucks (have their own freight matrix), agricultural vehicles (different travel times, no impact on peak hour capacities) , boats (only 28 trips in 2013, no intensity), planes (no effect on intensity) and the category 'other'.

Filtering trips to other countries, weekends, vacations and missing data
Some filtering is made to make the data ready for use.
- Trips originating or arriving outside the Netherlands are left out of the model. These trips are only 0,78% of all trips in OViN 2013 (after filtering out the trucks and airplanes).
- For 5% of the trips (OViN 2013) no arrival or destination was reported. These missing data is equally distributed over the modes. So, all relations where increased with 5%.
- For the model an average day is needed. Al weekends and holidays are filtered out. Weekends are filtered by neglecting Saturdays and Sundays. For holidays the CBS has a correction factor. Normally the annual amount of trips is divided by 365 to get the daily amount of trips, but with the correction factor this becomes 350 (Centraal Bureau voor de Statistiek 2014).

Comparison of the data with Scenario Explorer
In order to check the data collection method a check is made with the data the Scenario Explorer (SE) presents in part one of their report (1999a). In order to do so the data collection script is used on the OVG dataset of 1990, which is source for the base year of the ScenarioExplorer. All figures are in the same magnitude. Some points are discussed here below:
- The total amount km travelled is 5% higher in the SE, the total amount trips made is 5% shorter.
- In the SE more trips are made in the Randstad then in the OViN data. On the other hand, in the rural areas the less trips are reported in the OViN data.
- The modal splits of both reports differs less than 1%.

More checks are not possible, as this is the only data which is reported in the Scenario Explorer reports.

The data differs, however the differences are small. As the ScenarioExplorer does not report on their exact definition it's hard to explain where the differences come from. Heyma et al. explain they use a mix of "statistical sources (the OVG of the CBS) and models (like WOLOCAS2 of TNO Inro" (Heyma et al. 1999a, p.73) [44].

---

[44] Author translation from Ducth: "De basisgegevens zijn afgeleid uit bestaande statistische bronnen (bijvoorbeeld het OVG van het CBS) en bestaande modellen (zoals WOLOCAS2 van TNO Inro)"

Appendix B: Overview of municipalities and their zones

For the research the Netherlands is split up in 6 zones. These are the municipalities per zone. Municipality classifications of 2015 are used.

Large cities in the Randstad (LCR)

Amsterdam

Rotterdam

's-Gravenhage

Utrecht

Satellite towns of large cities in the Randstad (ST-LCR)

De Bilt

Bunnik

Houten

IJsselstein

Nieuwegein

Stichtse Vecht

Zeist

Amstelveen

Diemen

Barendrecht

Brielle

Capelle aan den IJssel

Leidschendam-Voorburg

Pijnacker-Nootdorp

Ridderkerk

Rijswijk

Schiedam

Vlaardingen

Wassenaar

Cities in the Randstad (CR)

Almere

Amersfoort

Haarlem

Zaanstad

Delft

Dordrecht

Leiden

Rest of the Randstad (RR)

The whole of Zuid-Holland, and

Baarn

Bunschoten

Eemnes

Leusden

Lopik

Montfoort

Oudewater

De Ronde Venen

Soest

Vianen

Wijk bij Duurstede

Woerden

Aalsmeer

Beemster

Beverwijk

Blaricum

Bloemendaal

Bussum

Edam-Volendam

Haarlemmerliede en Spaarnwoude

Heemskerk

Heemstede

Hilversum

Landsmeer

Laren

Oostzaan

Ouder-Amstel

Purmerend

Velsen

Weesp

Zandvoort

Cities in the rest of the Netherlands (CRN)

Groningen

Leeuwarden

Emmen

Enschede

Zwolle

Apeldoorn

Arnhem

Ede

Nijmegen

Alkmaar

Breda

Eindhoven

's-Hertogenbosch

Tilburg

Maastricht

Rest Netherlands (RN)

All other municipalities

Map with the 6 zones of the Netherlands

Large cities in the Randstad (LCR)
Satellite towns of large cities in the Randstad (ST-LCR)
Cities in the Randstad (CR)
Rest of the Randstad (RR)
Cities in the rest of the Netherlands (CRN)
Rest Netherlands (RN)
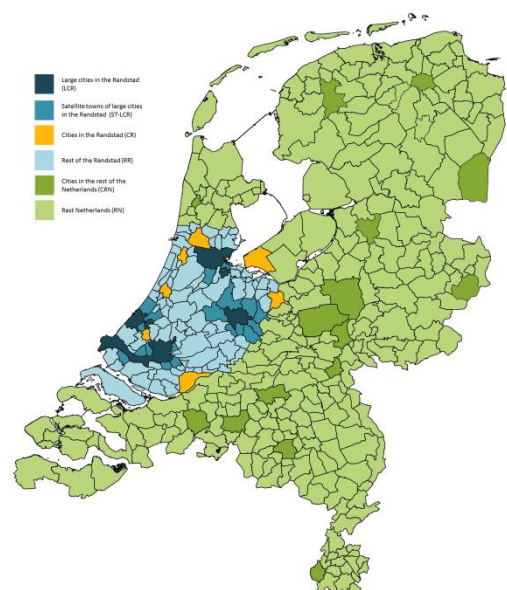
Appendix C: All exogenous variables

Trip generation, distribution and mode choice

Name	Unit	Source
% of car owners	-	Derivived from OViN 10-13
Amount of trips	Trips	Derivived from OViN 10-13
Constant Active modes	Euro	Estimated from OViN 10-13
Constant Active modes (no car)	Euro	Estimated from OViN 10-13
Constant BTM	Euro	Estimated from OViN 10-13
Constant BTM (no car)	Euro	Estimated from OViN 10-13
Constant Level 0	Euro	Estimated from OViN 10-13
Constant Level 1/2	Euro	Estimated from OViN 10-13 / assumption
Constant Level 3	Euro	Estimated from OViN 10-13 / assumption
Constant Train	Euro	Estimated from OViN 10-13
Constant Train (no car)	Euro	Estimated from OViN 10-13
Distance Active modes	km	Derivived from OViN 10-13
Distance BTM	km	Derivived from OViN 10-13
Distance Cars	km	Derivived from OViN 10-13
Distance depended costs Active modes	Euro/km	AVG 1994
Distance depended costs BTM	Euro/km	AVG 1994
Distance depended costs Level 0	Euro/km	AVG 1994
Distance depended costs Level 1/2	Euro/km	AVG 1994 / assumption
Distance depended costs Level 3	Euro/km	AVG 1994 / assumption
Distance depended costs passenger	Euro/km	AVG 1994 / assumption
Distance depended costs Train	Euro/km	AVG 1994
Distance Train	km	Derivived from OViN 10-13
Sensitivity Mode Choice Active modes	1/euro	Estimated from OViN 10-13
Sensitivity Mode Choice BTM	1/euro	Estimated from OViN 10-13
Sensitivity Mode Choice Car	1/euro	Estimated from OViN 10-13
Sensitivity Mode Choice Train	1/euro	Estimated from OViN 10-13
Travel Time Active modes	min	Derivived from OViN 10-13
Travel Time BTM	min	Derivived from OViN 10-13
Travel Time Passenger	Min	Travel time car OViN 2013
Travel Time Train	min	Derivived from OViN 10-13
Value of Time Active modes	Euro/min	KiM 2013 / Fietsberaad 2012
Value of Time BTM	Euro/min	KiM 2013
Value of Time Level 0	Euro/min	KiM 2013
Value of Time Level 1/2	Euro/min	KiM 2013 / assumption
Value of Time Level 3	Euro/min	KiM 2013 / assumption
Value of Time Passenger	Euro/min	KiM 2013 / assumption
Value of Time Train	Euro/min	KiM 2013

Time of day choice

Name	Unit	Source
Constant Time of Day	Euro	Estimated from OViN 10-13
Sensitivity Time of Day	1/euro	Estimated from OViN 10-13
Travel Time Car (off-peak, corrected)	min	Derivived from OViN 10-13

Trucks

Name	Unit	Source
% HGV in peakhour	-	CBS / INWEVA
Amount of trips HGV	#	INWEVA
PCU - factor	-	NRM / LMS, Minderhoud 2011
Rise of trips HGV	-	LMS GE output

Assignment

Capacity road	veh/h	Calibrated based upon OViN 10-13
Delay speed	Years	Assumption
Freeflow speed	km/u	Scenario Explorer / OViN 10-13
Overlapfactor	-	Scenario Explorer source code
Space level 1/2 car takes in on the road	-	Many literature sources (see H8)
Space level 3 car takes in on the road	-	Many literature sources (see H8)
Start speed	km/h	Derivived from OViN 10-13
Urbanisation factor	-	Scenario Explorer

Exogenous changing factors

Name	Unit	Source
% of level 0 cars	-	Nieuwenhuizen 2015
% of level 0 HGV	-	Nieuwenhuizen 2015 / assumption
% of level 1 and 2 cars	-	Nieuwenhuizen 2015
% of level 1 and 2 HGV	-	Nieuwenhuizen 2015 / assumption
% of level 3 cars	-	Nieuwenhuizen 2015
% of level 3 HGV	-	Nieuwenhuizen 2015 / assumption
Change in car costs	-	LMS starting points documents
Change in people in a car	-	LMS GE output
Change in public transport costs	-	LMS starting points documents
Demographic growth	-	PBL 2013
Faster trains	-	LMS starting points documents / PHS
Growth of the capacity per year	-	Assumed based upon highway expansion between '14-'17

Appendix D: Extreme value test

Goal of this test is to check physical laws. And see if equations also hold under extreme conditions. For all tests a *lab environment* is used. This means that the world stays like it is in 2010, for one aspect: the introduction of automated vehicles.

Summary of the results
Passengers can travel when there are no cars – or with too many passengers per car
Car drivers and car passengers are separate modes in the model, without a connection. The only link is that their travel times and distances are the same. So if cars get unattractive and passengers attractive, the model simulates too many passengers per car (more than 4) or even passengers without any cars. The case that this would happen is rare, as the main reason for cars to get unattractive is due to high travel times, which also make being a passenger unattractive. Very high fuel costs or an extreme change in value of time for one of both can lead to impossible situations. In the LMS, and many other macroscopic models, the modes are also not linked, so this problem might also arise.

With extreme population growths the model starts oscillating
When the population grows with more than 15% per year, the speeds and the amount of people traveling during peak hours start oscillating. Due to the rise in population roads start to congest and speeds drop. Therefore no one takes the car anymore and the speeds rise immediately. This flip-flopping effect does not occur in normal behaviour as the growth is normally around 0,3 till 0,8% per year. If a smaller time step is chosen this effect arises with higher percentages of growth. With a time step of 0.0078125 (3 days) this effect arises at doubling in population (100% growth) per year. A smaller time step is not used in the model as the cases in which it is needed are very rare, and it has an effect on the calculation time.

With extreme inputs the model needs 5 years to stabilise
When the input parameters in the year 2000 (the start of simulation, warm-up till 2013)[45] are extreme the model takes 5 years to stabilise. As the modal split in 2000 is calculated with an exogenous road speed (road speed from OViN, on which the capacity is also calibrated), a change in capacity, free-flow speed or utility of a mode changes the output after one time step considerably. Within 5 years this unbalance is stable again. It is unlikely that effect occurs within normal simulations, since all exogenous changes are spread out over time and not at the start of the modelling. Still, if one would like to simulate the effects of an instant population doubling, the model would show extreme results. For less extreme cases the model stabilises more quickly. The time step has no influence on the amount of years to stabilise. This has to do with the delay of the feedback.

When the peak gets very unattractive car usage rises
When the peak is very unattractive (not due to low speeds, but due to a high constant, for instance by road pricing), less cars drive during peak hours. Due to this rise in speeds during peak hours, and as cars move to the shoulders of the peak, speeds will probably drop outside of the peak. However,

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[45] The base year of the model is 2013. However, as in the tests the input parameters vary and different scenarios are tested a warm-up period is introduced. From 2000 on the model can stabilise. This is done to prevent small errors if input differs.

the utility of the car is calculated based upon speeds during peak hours, so cars get more attractive. So, the model only holds if the speeds during peak hours are lower than (or around) the speeds outside the peak. In the Netherlands almost all models are peak hour models, which use this assumption.

Neutral

This table shows the behaviour without sensitivities. In all coming figures, as well as in these below, the connected scenario is used as case.

High	Low

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed

Average speed in peak on the road : Current
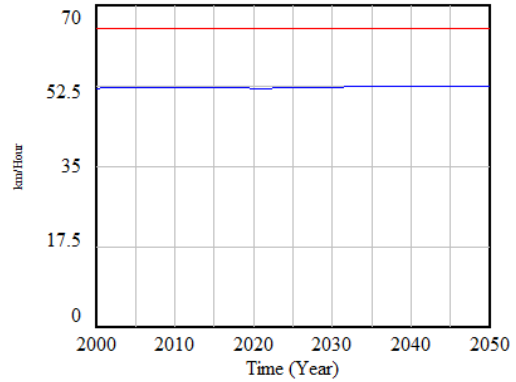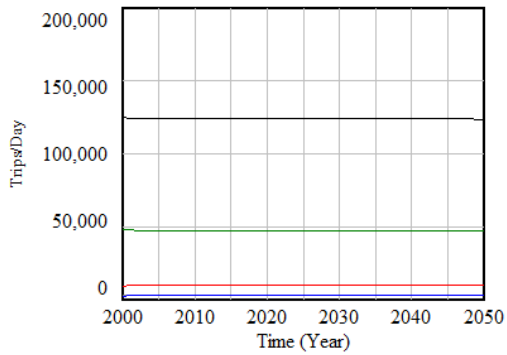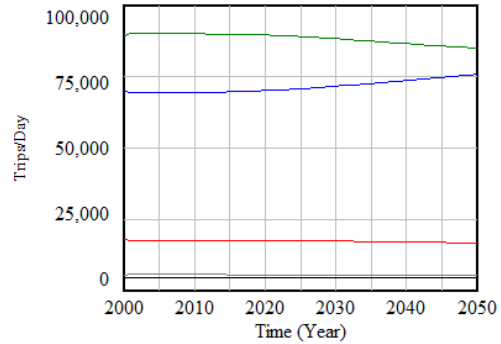Freeflowspeed : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current

Set-up: For the high scenario the growth is 40% per year for both the population as the amount of trucks in the model. For the low scenario this is -40% per year.

Results: The high run gives answers as expected. The road congests, and everyone uses the train (as the other modes have a unrestricted capacity). Compared to the real world you also would find a congested train, BTM and slow traffic. Also an oscillating effect can be seen. As no people use a car due to high travel times, the travel times drop, and some switch modes, which again lead to high travel times. This effects occurs at growth percentages of >15%. In a normal scenario the population growth is 0,3 per year. The low run gives also logical answers, in 15 years there is no population left, and no trips are made anymore.

Free flow speed

High	Low

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed

Average speed in peak on the road : Current
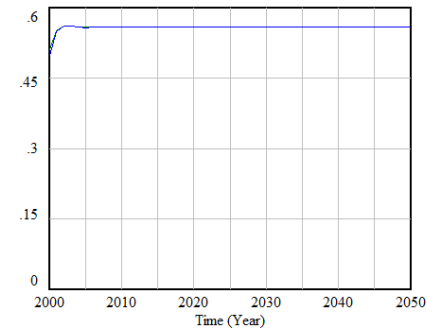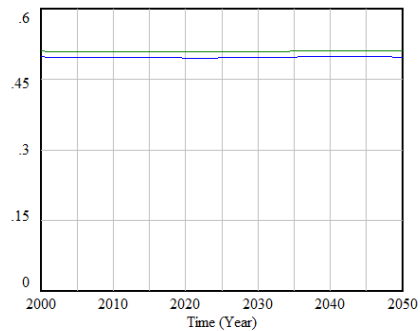Freeflowspeed : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split
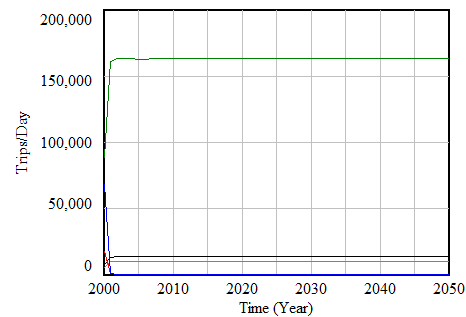
Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: In the high run the free-flow speed is 1000 km/h, in the low run the free-flow speed is 8 (lower speeds lead to an floating point error in the time of day choice).

Results: Due to higher speeds cars get more attractive, due to lower speeds they get less attractive. The amount of passengers also rises / drops due to changes in free-flow speeds. The peak at the start for the peak hours is logical as than the start speed off-peak (free-flow) is lower than the start speed in the peak (the OViN speed). This immediately drops as the speeds are way lower than the OViN speed.
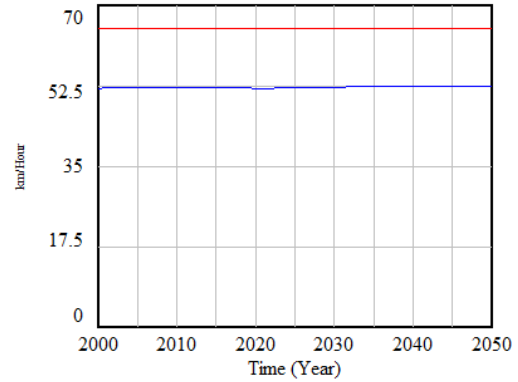
Capacity road

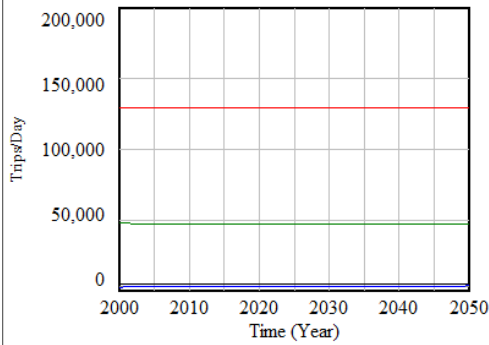| High	Low

Average speed

Average speed in peak on the road : Current
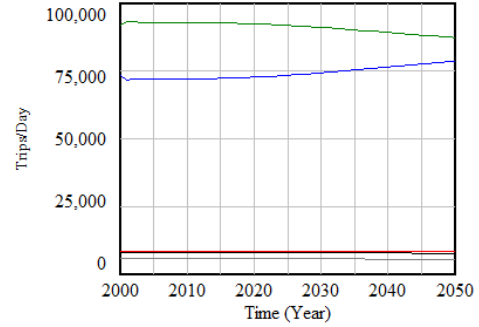Freeflowspeed : Current

Average speed

Average speed in peak on the road : Current
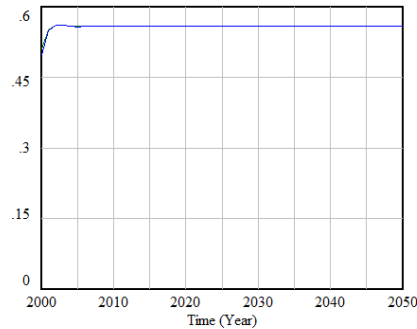Freeflowspeed : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current
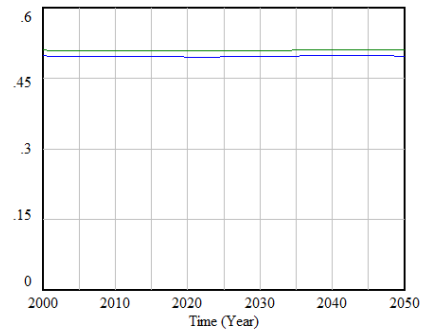
Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: in the high scenario the roads are expanded with 40% a year, in the low scenario 40% of the roads is broken down every year.

Results: Results for both the high and low scenario are logical. One small aspect is that the speeds in the low scenario are around 0 but not zero. This is because the BPR function which is used for the assignment consists of 20 points, from which the last point is not zero, but almost zero. This means that if there are an infinite number of cars on the road the speeds are still not zero. This is done because a floating point error occurs when the BPR function gives a zero as outcome. For the mode choice and time of day this does not lead to problems. These functions give values close to zero $(1*10^{-12})$ as outcomes for the amount of cars and the amount of people driving in the peak.

Space level 1/2 car takes in on the road & Space level 3 car takes in on the road

High	Low

Set-up: For the high scenario level 1,2 and 3 vehicles only take 10% of a normal car. For the low scenario they take 10 times more space than a normal car.

Results: The results are logical and as expected.

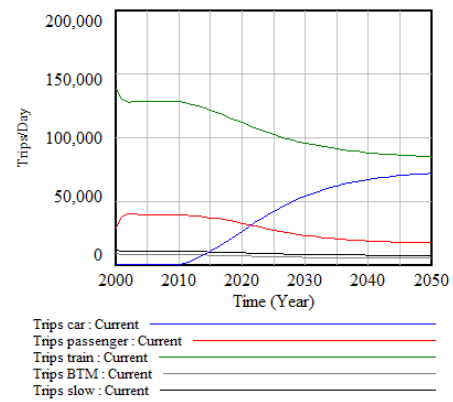| High	Low

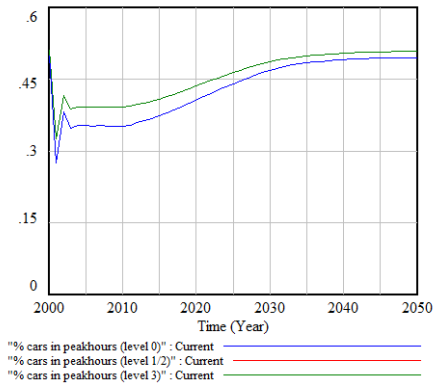### Average speed

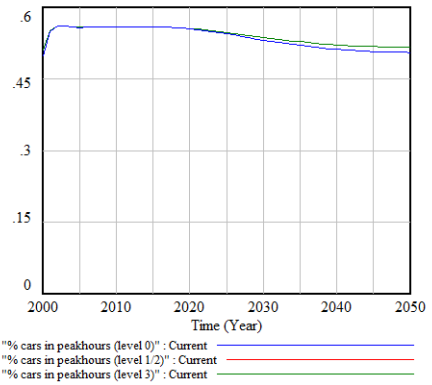
Average speed

Modal Split

Modal Split

Trips made in peakhours

Trips made in peakhours

Set-up: For the high scenario the disutility is 0, so the train becomes more attractive. In the low scenario the disutility is 5 times as high as normal.

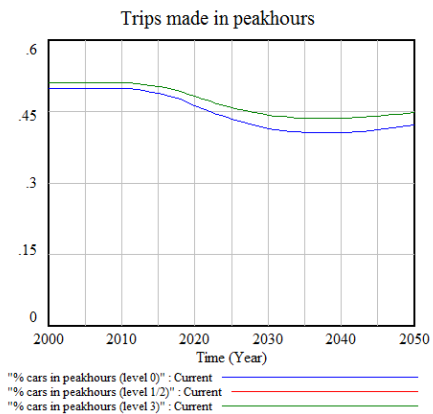**Results:** Striking is the sudden peak in average speed at the start of the low scenario. As many train passengers take a car and see the travel times go up of the car. Two mechanisms are activated, people tend to travel off-peak, and change modes. The time of day mechanism is looks stronger, but the change in modal split is divided over 4 modes, and is equally strong.

Utility BTM

High	Low

Average speed (High)

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed (Low)

Average speed in peak on the road : Current
Freeflowspeed : Current

Modal Split (High)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split (Low)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours (High)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours (Low)

"% cars in peakhours (level 0)" : Current
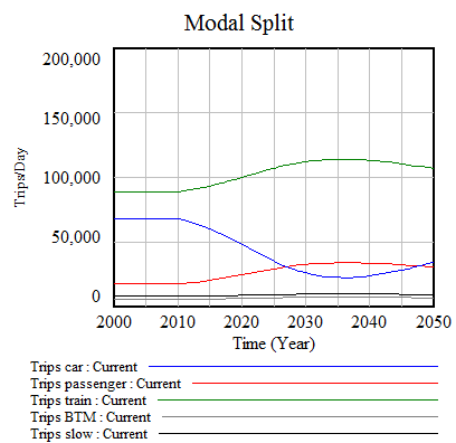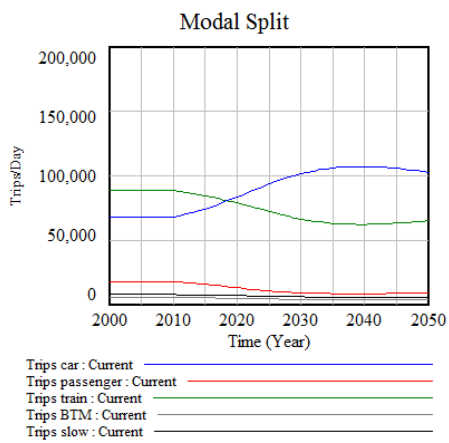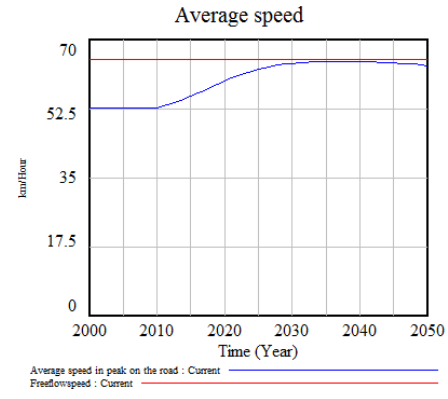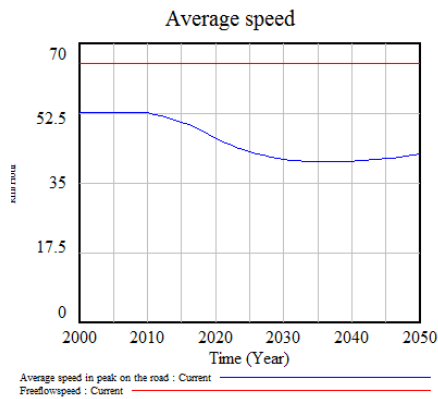"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: For the high scenario the disutility is 0, so BTM becomes more attractive. In the low scenario the disutility is 5 times as high as normal.
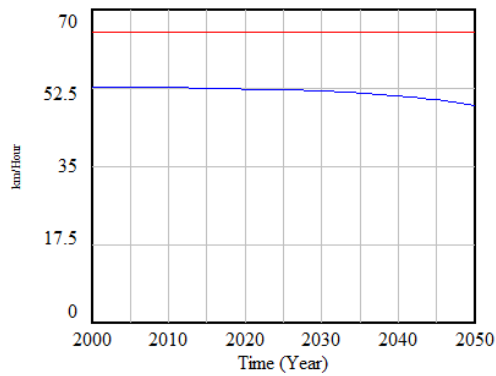
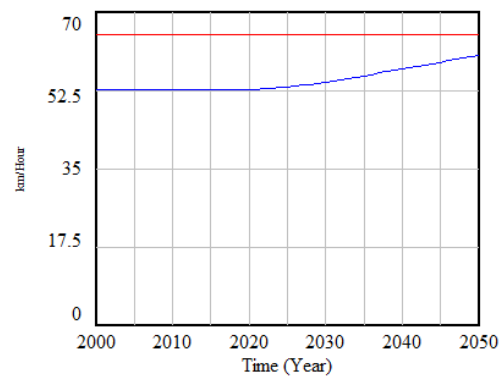**Results:** The results show are logical and as expected.

Utility Slow

High	Low

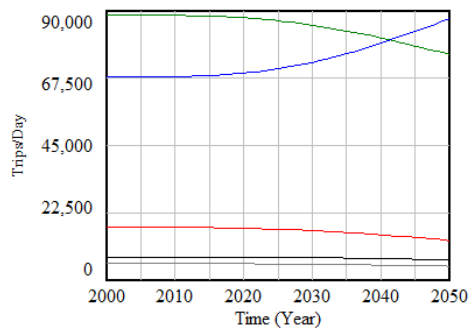### Average speed (High)

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed (Low)

Average speed in peak on the road : Current
Freeflowspeed : Current

Modal Split (High)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split (Low)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours (High)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours (Low)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: For the high scenario the disutility is 0, so cycling or walking becomes more attractive. In the low scenario the disutility is 5 times as high as normal.

Results: The results show are logical and as expected.

High	Low

Average speed (High)

Average speed in peak on the road : Current
Freeflowspeed : Current
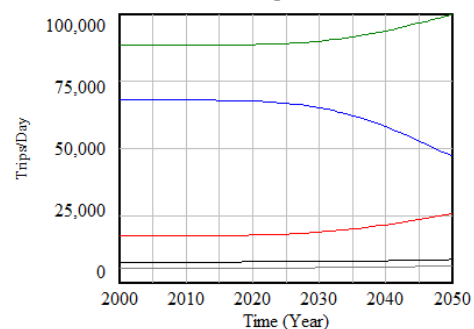
Average speed (Low)

Average speed in peak on the road : Current
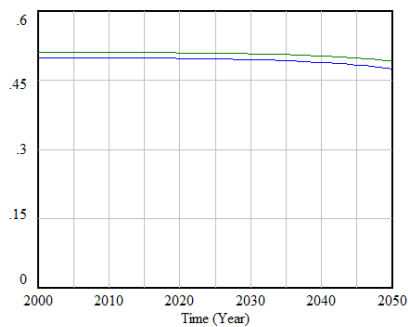Freeflowspeed : Current

Modal Split (High)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current
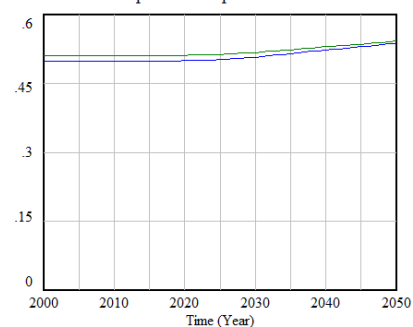
Modal Split (Low)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours (High)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours (Low)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: For the high scenario the disutility is 0, so being a passenger becomes more attractive. In the low scenario the disutility is 5 times as high as normal.
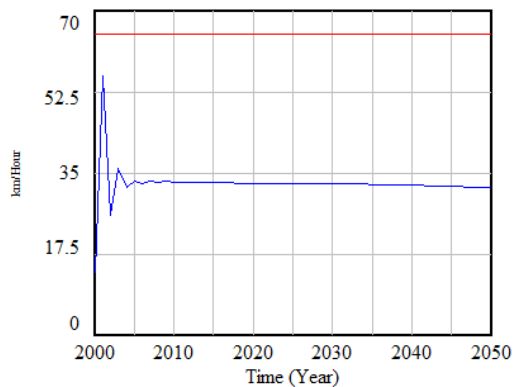
Results: The results show are logical and as expected.

Utility Level 0

High	Low

Average speed (High)
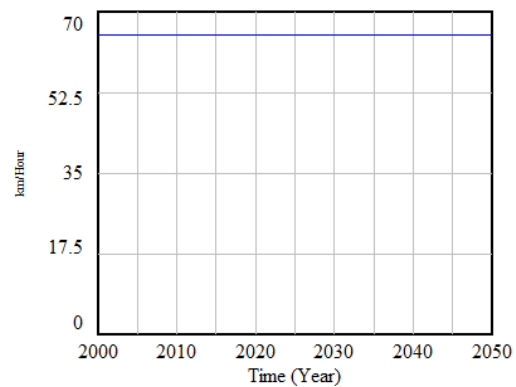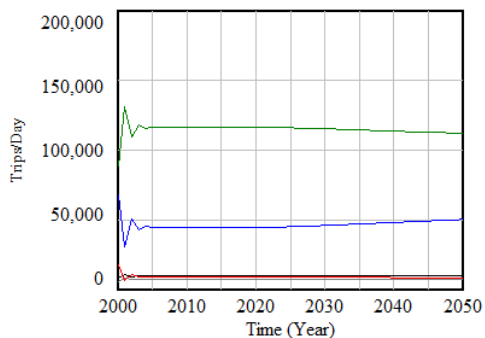

Average speed in peak on the road : Current
Freeflowspeed : Current
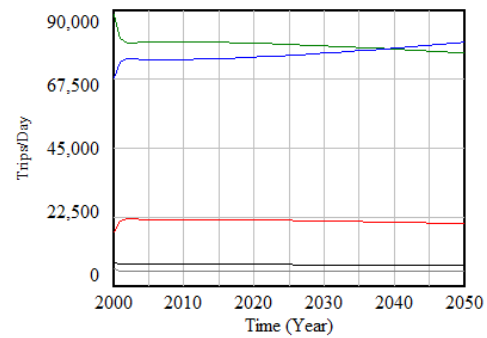
Average speed (Low)

Average speed in peak on the road : Current
Freeflowspeed : Current

Modal Split (High)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split (Low)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours (High)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours (Low)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: For the high scenario the disutility is 0, so the level 0 cars become more attractive. In the low scenario the disutility is 5 times as high as normal.

Results: The results show are logical and as expected.

High	Low

Average speed (High)

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed (Low)

Average speed in peak on the road : Current
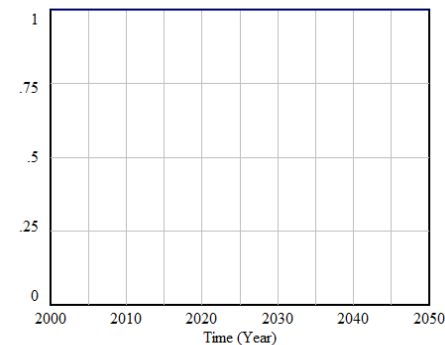Freeflowspeed : Current

Modal Split (High)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current
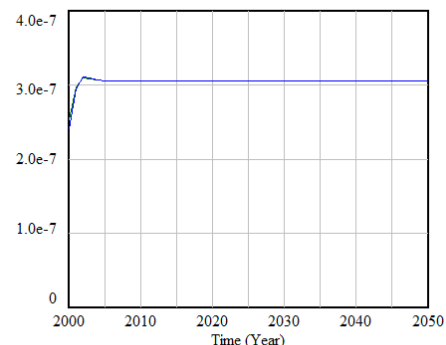
Modal Split (Low)

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours (High)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours (Low)

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: For the high scenario the disutility is 0, so level 1 & 2 cars get more attractive. In the low scenario the disutility is 5 times as high as normal.

Results: The results show are logical and as expected.

Utility Level 3

High	Low

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: For the high scenario the disutility is 0, so level 3 cars become more attractive. In the low scenario the disutility is 5 times as high as normal.

Results: The results show are logical and as expected.

High	Low

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: The constant for driving in the peak is set on +100 and on -100.

Results: The results are logical, when the peak is very attractive every car drives in the peak, when the peak has a low utility, no one drives there. As no one drives in the peak the speeds for the car rise, and it gets more attractive. Having no cars in the peak would probably lead to problems outside the traditional peak hours, so a new assignment should be made for outside the peak. So the model only holds if the average speed in the peak is lower than outside the peak. If due to large societal changes would occur and the peaks disappear another the model would need a reshape.

Appendix E: Sensitivity test

In this sensitivity analysis is checked if the numerical values and the behaviour changes due to changes in the inputs (Sterman 2000, p.861). An input change of +10% and -10% is simulated together with the normal behaviour. On 9 parameters this analysis is performed. Some of these are groups of parameters, such as the utility, which is calculated from several parameters. In this case a multiplier is added, which normally is 1, but varies from 0,9 till 1,1.

Summary of the results
For almost all simulations the results are logical. If the inputs are varied 10%, the outputs do the same. However, a few points are striking.

The first 5 years the model needs to stabilize
Just as is shown in the extreme value analysis, the model needs to stabilize in the first five years. As the modal split in 2000 is calculated with a exogenous road speed (road speed from OViN, on which the capacity is also calibrated), a change in capacity, free-flows peed or utility of a mode can bring the start in unbalance. Also with an input change of 10% this needs some years to stabilize. This is not harmful for the model as analysis are performed from the year 2013, and the model starts running in 2000. However, in the experimentation the first years might show to some oscillation.

Time of day choice is less sensitive than the mode choice
Where the mode choice roughly changes 10% due to changes in speed on the roads or utilities, the time of day choice only changes 5%. It seems that the mode choice is most sensitive. One could argue that changing the preference for traveling in- or off-peak is not that hard as changing modes. However, the opposite can also be defended: a change in departure time (peak is 2 hours, so you would have to change your departure time on average 30 min), can be hard as offices or schools often have rigid starting times.

Symmetric changes in utilities show asymmetric outputs in speeds and mode choice
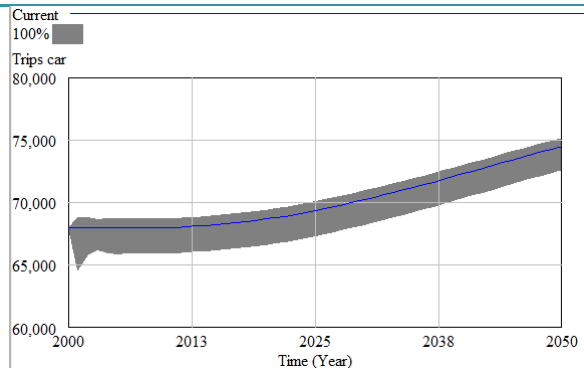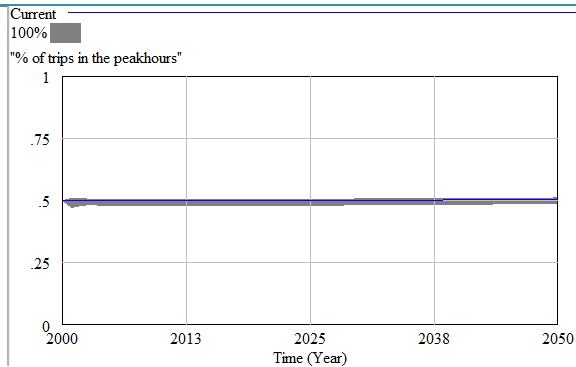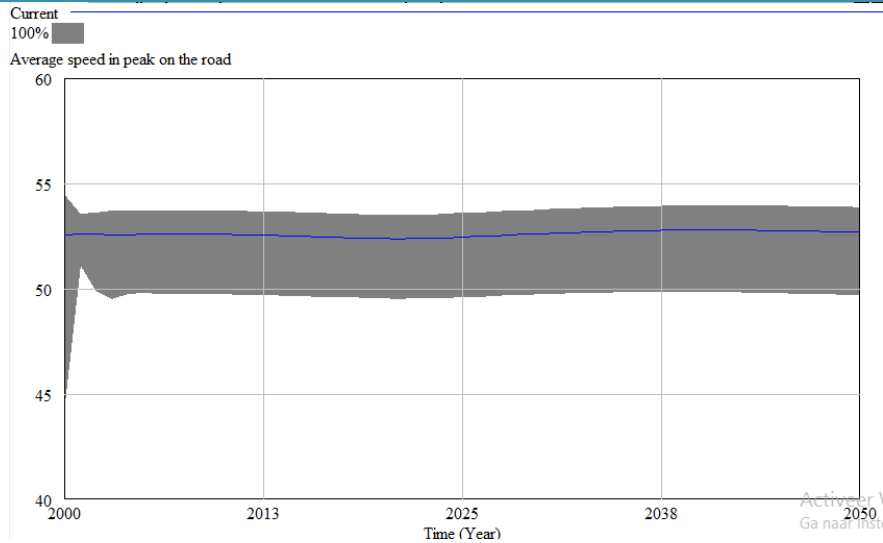When for instance utilities are changed + and – 10% the speeds and mode choice show a asymmetric pattern. This seems strange, but can be explained. Both have another reason. The form of the speed-flow curve makes that less car traffic leads to a slightly higher speeds, but more car traffic leads to a lot lower speeds. For the preference in mode choice a same pattern can be seen, however then due to the exponential term in the utility functions.

Neutral

This table shows the behaviour with without extremes.

Average speed

Average speed in peak on the road : Current
Freeflowspeed : Current

Zelfrijdende auto's

"% level 0 bezitters" : Current
"% verplaatsingen level 1 and 2 bezitters" : Current
"% verplaatsingen level 3 bezitters" : Current

Modal Split

Trips car : Current
Trips passenger : Current
Trips train : Current
Trips BTM : Current
Trips slow : Current

Trips made in peakhours

"% cars in peakhours (level 0)" : Current
"% cars in peakhours (level 1/2)" : Current
"% cars in peakhours (level 3)" : Current

Set-up: The capacity of the road is from the start year raised with 10% and lowered with 10%.

Results:

What can be seen is that the drop in speeds is higher than the rise in speeds. This is logical as due to the form of the BPR function. Also can be seen that the time of day choice is less sensitive than the mode choice. Here only outputs of 5% are shown when the inputs differ 10%. This does not have to be wrong, but the sensitivities of both the mode and time of day choice should be in balance. The third aspect which can be seen are the sudden drops and peaks at the start. This is due to initial values. This also can be seen for the extreme value tests. As analysis with the model are performed from 2013 onwards the peaks in the beginning are not harmful for the use of the model.
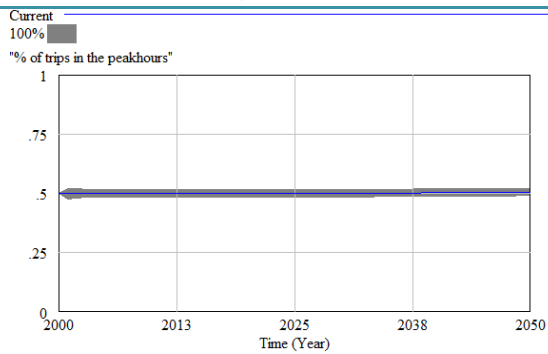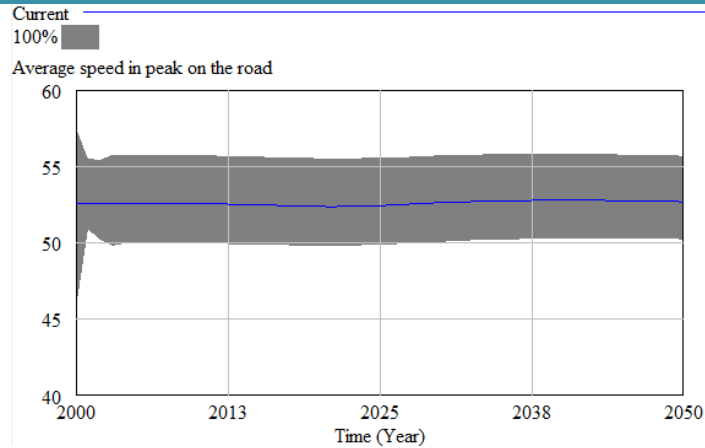
Free-flow speed
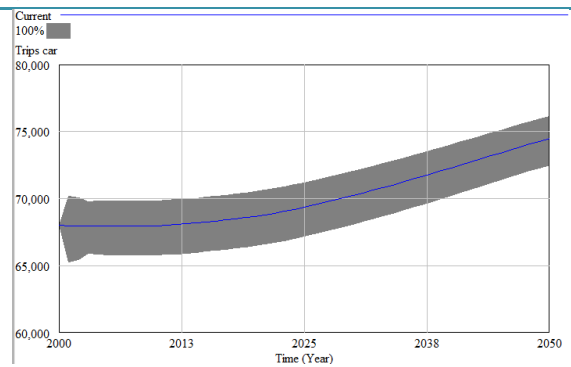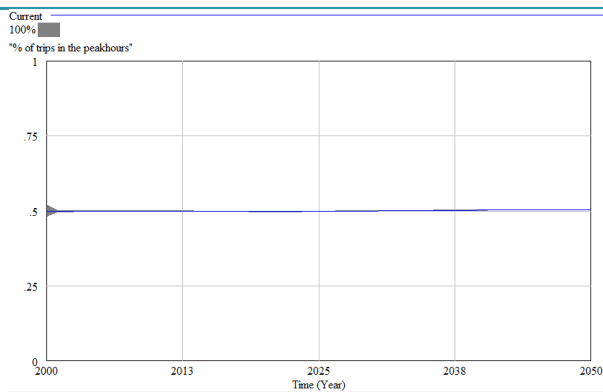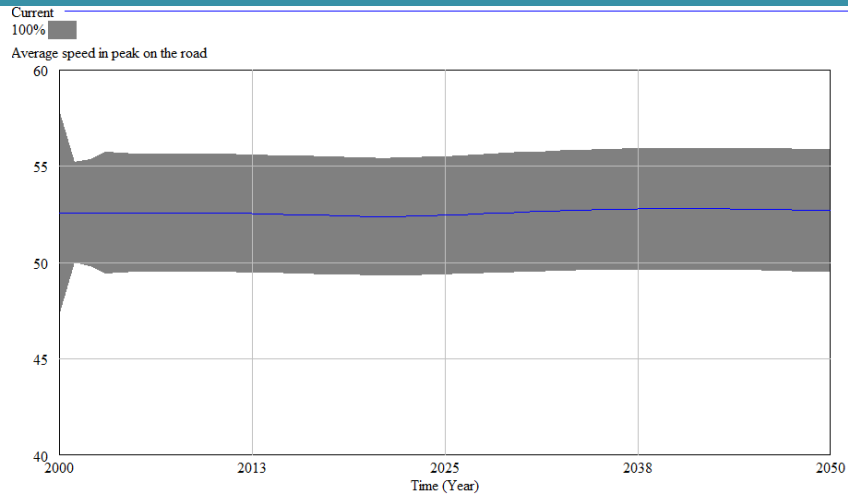
Set-up: The free-flow speed is from the start year raised with 10% and lowered with 10%.

Results:

Here again the same results can be seen. A very small effect on the time of day choice, and a logical effect on the mode choice. The time of day choice is determined by the difference in free-flow speed and the actual speed. As they are also related in the assignment a change in free-flow speed does not lead to a change in time of day choice.

Utility train

Current 100%

Average speed in peak on the road

Current 100%

"% of trips in the peakhours"

Current 100%

Trips train

Current 100%

Trips car

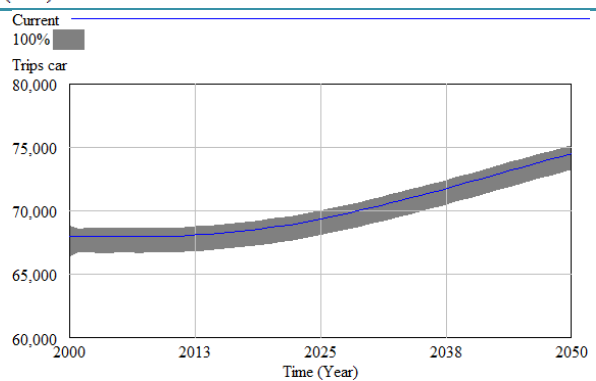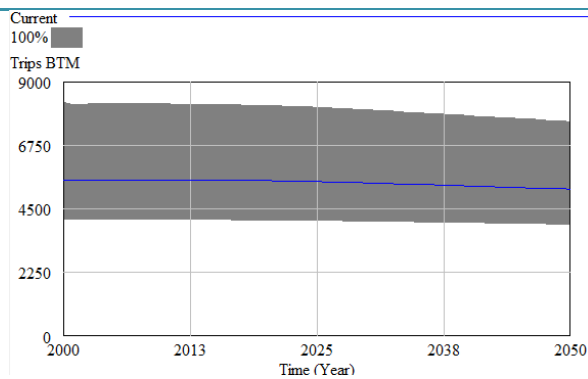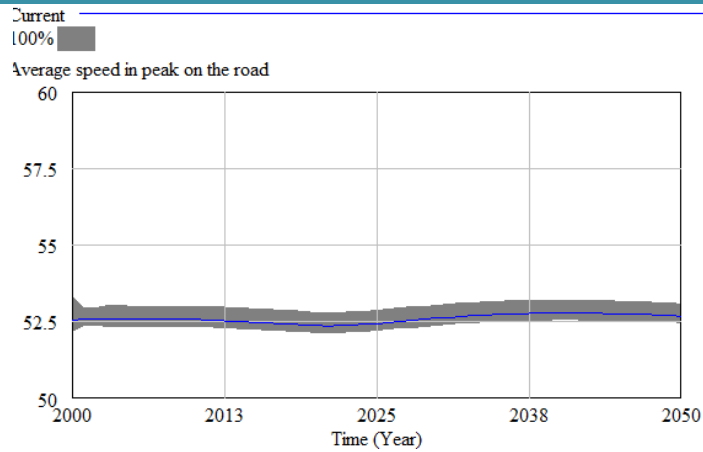Current 100%

Trips passenger
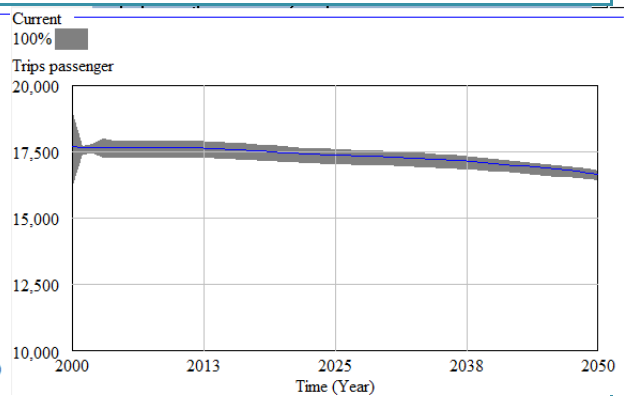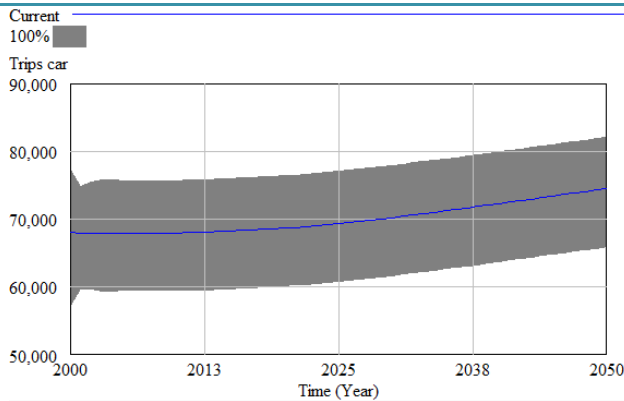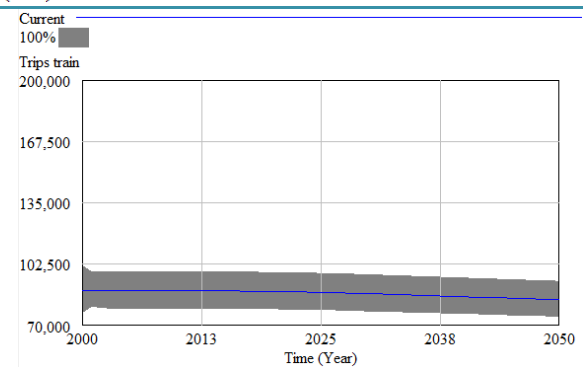
Set-up: The utility of the train is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:

Due to the exponential element in the logit function the change in mode choice is higher than 10%. It can be seen that the train and the car are quite related, as they are the two most populair modes of transport.

Utility BTM

Current
100%

Average speed in peak on the road

Current
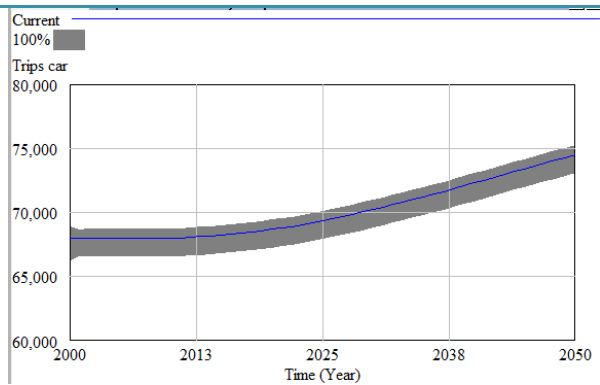100%
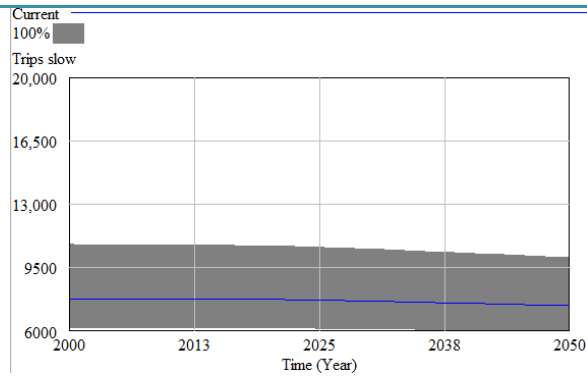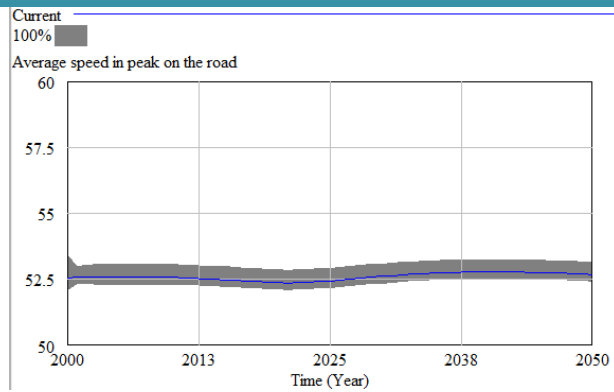
Trips BTM

Current
100%

Trips car

Set-up: The utility of BTM is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:

The same type of results can be seen as in the change in utlity for the train.

Utility Slow

Current
100%

Average speed in peak on the road

Current
100%
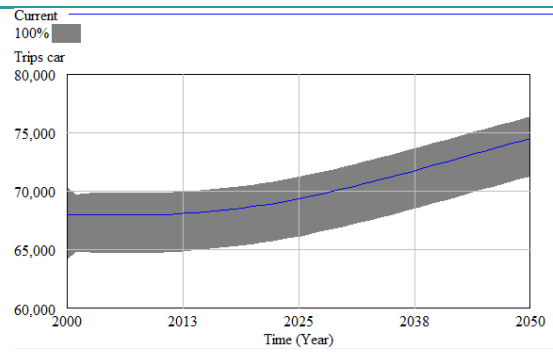
Trips slow
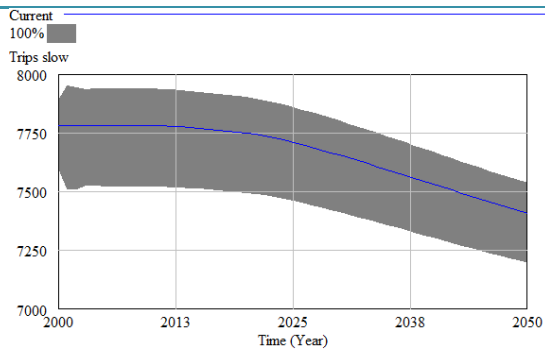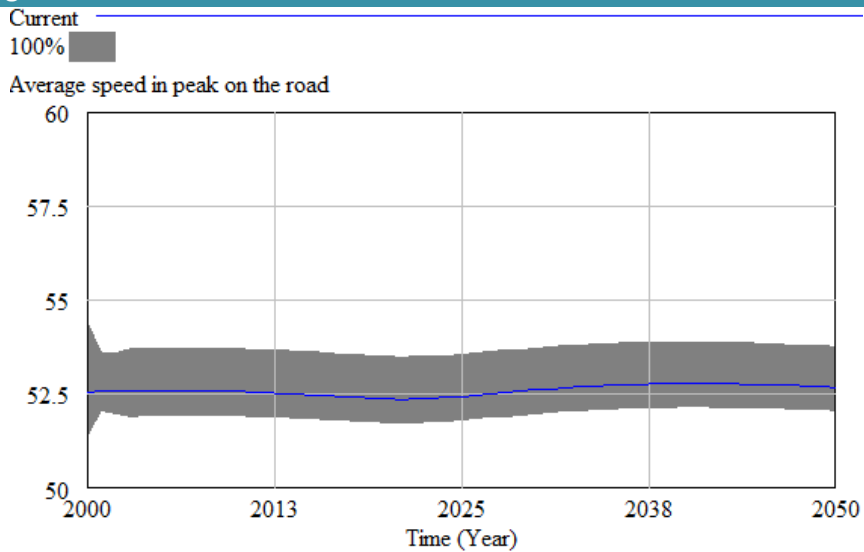

Current
100%

Trips car

Set-up: The utility of the slow traffic is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:

The same type of results can be seen as in the change in utlity for the train or BTM.

Utility Passenger

Current
100%

Average speed in peak on the road

Current
100%
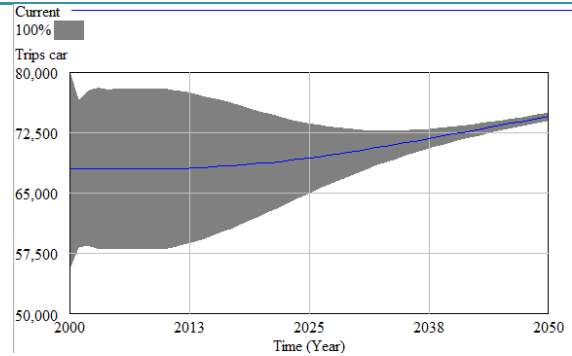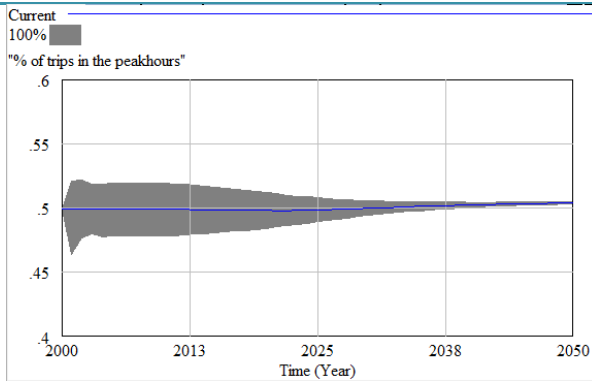
Trips slow

Current
100%

Trips car

Set-up: The utility of the passengers is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:
The same type of results can be seen as in the change in utlity for other modes.

Utility level 0

Current 100%

Average speed in peak on the road

Current 100%

"% of trips in the peakhours"

Current 100%

Trips car

Set-up: The utility of level 0 vehicles is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:
The same type of results can be seen as in the change in utlity for the train. Only difference is that the amount of level 0 vehicles decreases overtime and therefore the bandwiths also decrease.
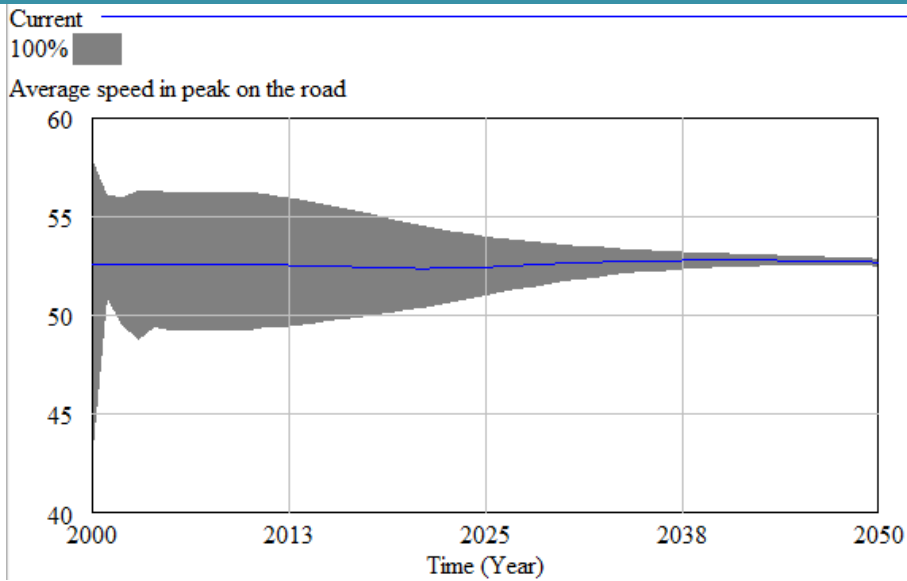
Utility level 1/2

Current 100%

Average speed in peak on the road

Current 100%

"% of trips in the peakhours"

Current 100%

Trips car

Set-up: The utility of level 1 /2 vehicles is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:

The same type of results can be seen as in the change in utlity for other modes. Only difference is that the amount of level 1 /2 vehicles changes overtime and therefore the bandwiths also changes. As there are never only level 1 / 2 vehicles the bandwithds are smaller than the level 0 cars (who start with 100% penetration rate.
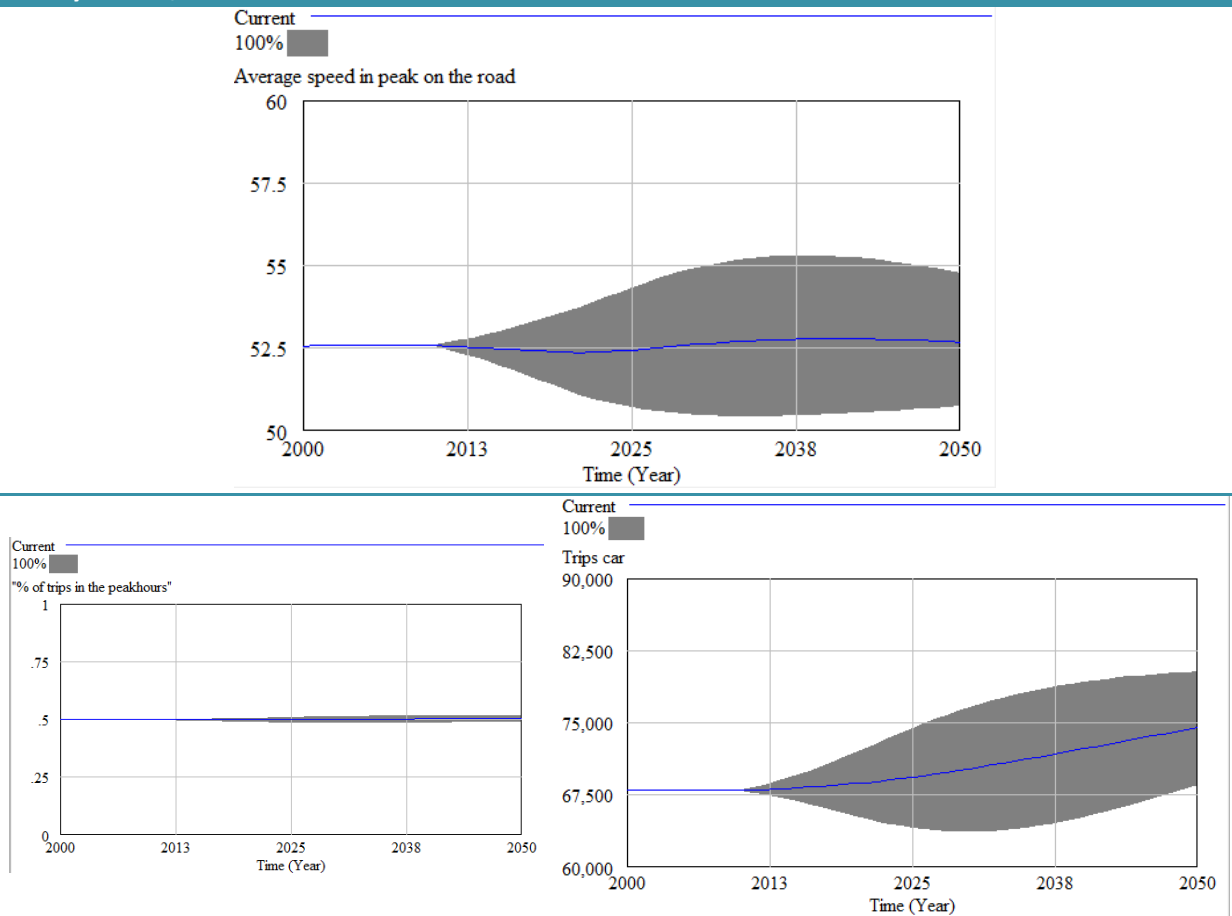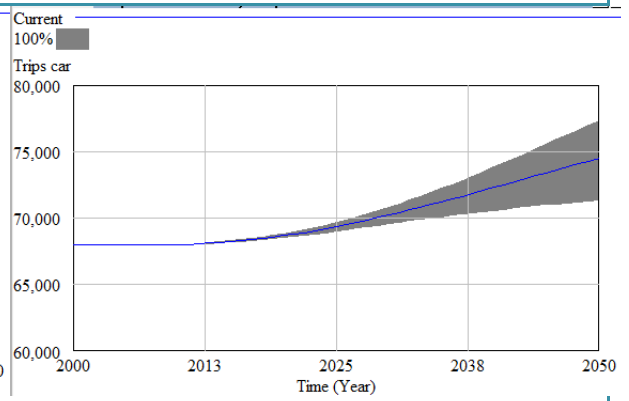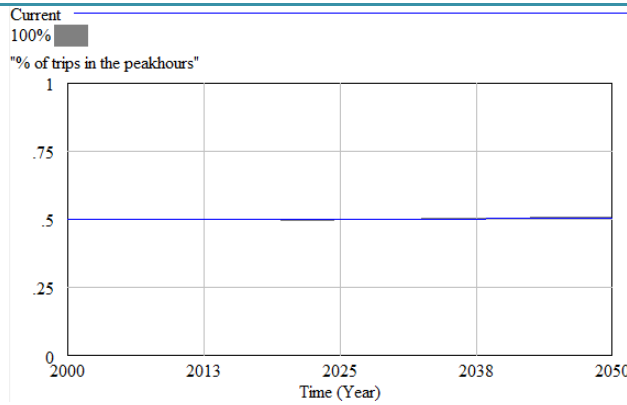
Utility level 3
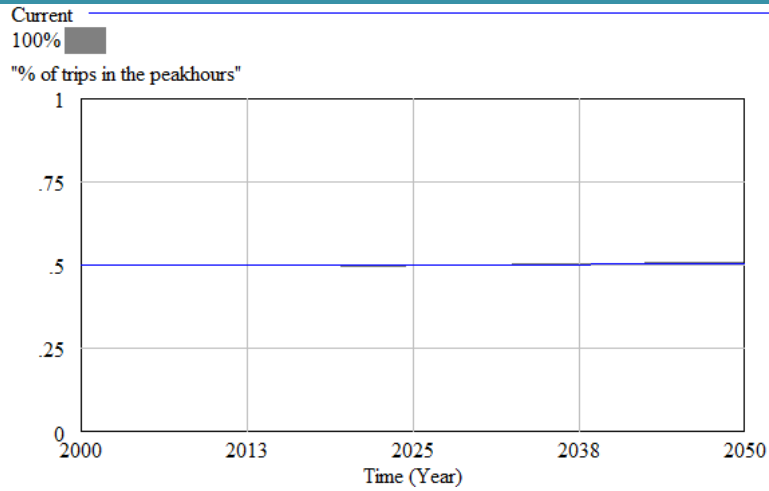
Set-up: The utility of level 3 vehicles is from the start year raised with 10% and lowered with 10%. To do so an extra factor is added to the utility function. In the normal scenario this factor is 1 and differs from 0,9 till 1,1.

Results:

The same type of results can be seen as in the change in utlity for other modes. Only difference is that the amount of level 1 /2 vehicles changes overtime and therefore the bandwiths also changes. As there are never only level 1 / 2 vehicles the bandwithds are smaller than the level 0 cars (who start with 100% penetration rate.

Appendix F: Experiments with the model

Model inputs : automated vehicles

Changes in value of time	Road type	Autonomous and Cooperative	
		Expected [%]	Upper and lower bound
Level 0	all	100	
Level 1 & 2	all	100	
Level 3	Inner city	100	
	Rural	90	80-100
	Provincial	90	80-100
	Between cities	80	70-90

		Autonomous (A_L)		Cooperative (C_L)		
		Expected [-]	Upper and lower bound	Expected [-]		Upper and lower bound
Level 0	all	1			1	
Level 1 & 2	Inner city	1	$1.1 - 0.9$		1	$1.1 - 0.9$
	Rural	1	1.05 - 0.95		1	1.05 - 0.95
	Provincial	1	1.05 - 0.95		1	1.05 - 0.95
	Between cities	1	1.05 - 0.95	[0-40%]	1	
				[40-100%]	Decreases till 0.95	$1 - 0.8$
Level 3	Inner city	0.95	$1.1 - 0.9$	0.95		$1.1 - 0.9$
	Rural	1	1.05 - 0.95	[0-40%]	1	
				[40-100%]	Decreases till 0.95	$1 - 0.9$
	Provincial	1	1.05 - 0.95	[0-40%]	1	
				[40-100%]	Decreases till 0.95	$1 - 0.9$
	Between cities	1	1.05 - 0.95	[0-40%]	1	
				[40-100%]	Decreases till 0.9	$1 - 0.7$

Fuel economy benefits		Autonomous & cooperative	Extra benefit for cooperative (arise after 40% penetration)
Level 0	all	0	0
Level 1 & 2	all	-5%	0
Level 3	Inner city	-5%	0
	Rural	-5%	-5%
	Provincial	-5%	-5%
	Between cities	-5%	-10%

Inputs

	Zone 1	Zone 21	zone 36	Zone 37
Capacity	315000	324000	1838000	118240
Amount of trips	4811855	300897	19350690	187464
Free flow speed	35	50	50	65
Urbanisation factor	3	2	3	1
% car owners	43,04%	71,36%	65%	66,43%

Relation 1 – Lab environment – Autonomous
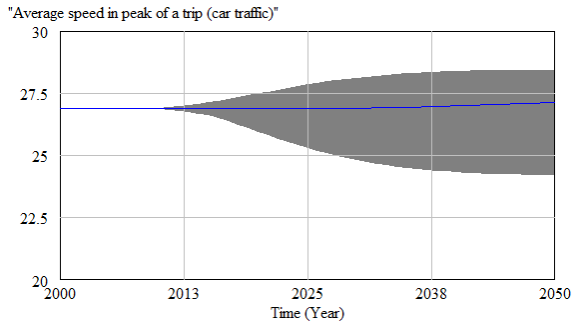
5. Average speed of a trip by car (km/h)	6. Car trips in the peak hours[%]
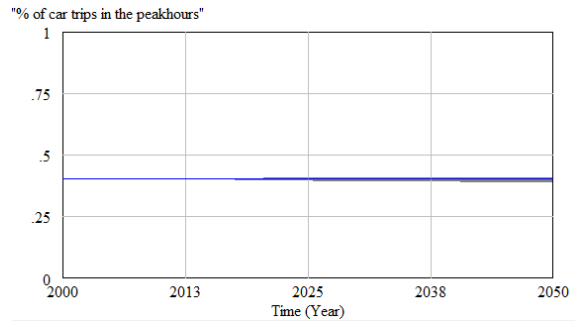
7. Modal split [# trips]
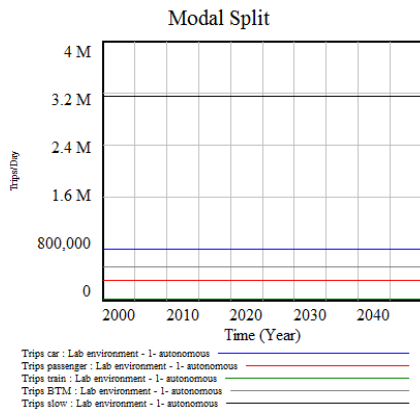
	2013	**2050**
Trips car	788400	795200 [1%]
Trips passenger	311300	311000 [0%]
Trips train	31720	31650 [0%]
Trips BTM	522000	521300 [0%]
Trips slow	3159000	3153000 [0%]

4. Loss hours corrected for value of time [€]	8. Average speed on a relation [km/h]

Speeds		Loss hours	
	2013		**2050**
Average speed in peak of a trip (car traffic)	26,88		27,14 [1%]
Average speed on a relation	13,58		13,66 [1%]
% of car trips in the peak hours	0,4035		0,4044 [0%]
Loss hours in a peak (VOT corrected)	49400		47970 [-3%]
Loss hours in a peak	329300		319800 [-3%]

Relation 1 – Lab environment – Cooperative
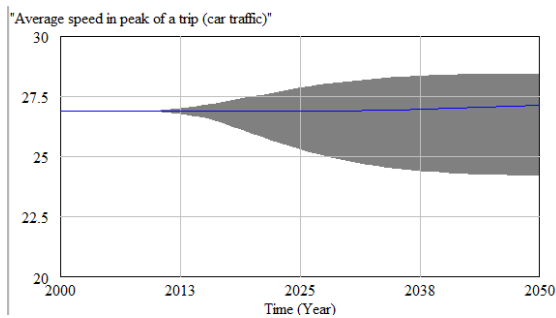
1. Average speed of a trip by car (km/h)	2. Car trips in the peak hours[%]
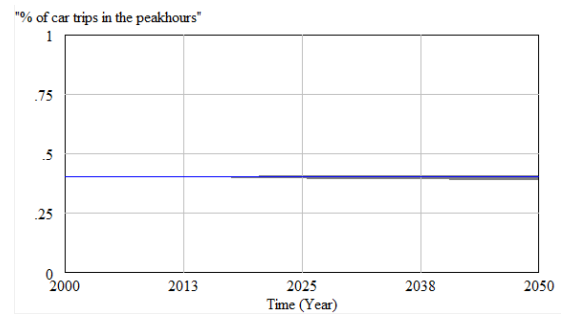
3. Modal split [# trips]		
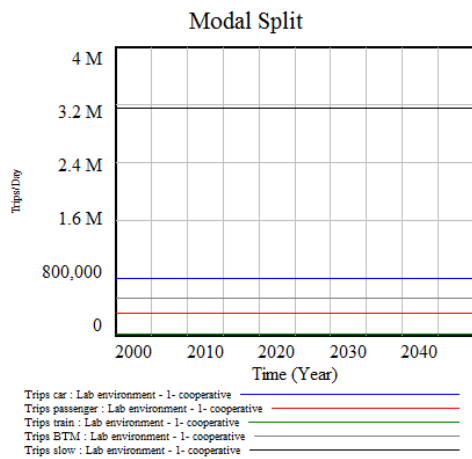
	2013	2050
Trips car	788400	795200 [1%]
Trips passenger	311300	311000 [0%]
Trips train	31720	31650 [0%]
Trips BTM	522000	521300 [0%]
Trips slow	3158000	3153000 [0%]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]
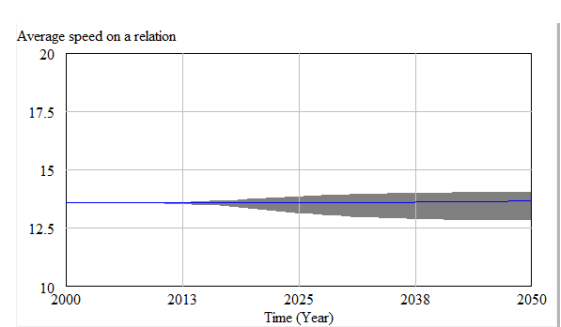
Speeds	Loss hours	
	2013	**2050**
Average speed in peak of a trip (car traffic)	26,88	27,14 [1%]
Average speed on a relation	13,58	13,66 [1%]
% of car trips in the peak hours	0,4035	0,4044 [0%]
Loss hours in a peak (VOT corrected)	49400	47970 [-3%]
Loss hours in a peak	329300	319800 [-3%]

Relation 21 – Lab environment – Autonomous

1. Average speed of a trip by car (km/h)	2. Car trips in the peak hours[%]

"Average speed in peak of a trip (car traffic)"

"% of car trips in the peakhours"

3. Modal split [# trips]

Modal Split

Trips car : Lab environment - 21- autonomous
Trips passenger : Lab environment - 21- autonomous
Trips train : Lab environment - 21- autonomous
Trips BTM : Lab environment - 21- autonomous
Trips slow : Lab environment - 21- autonomous
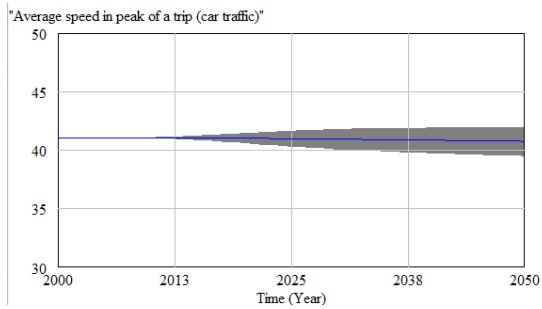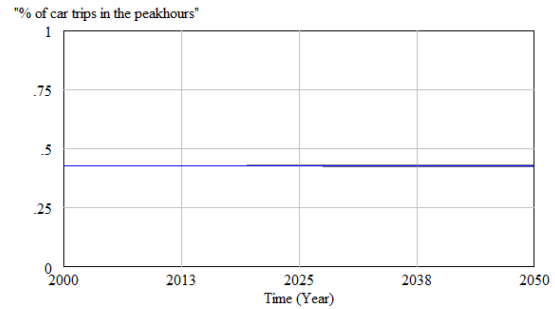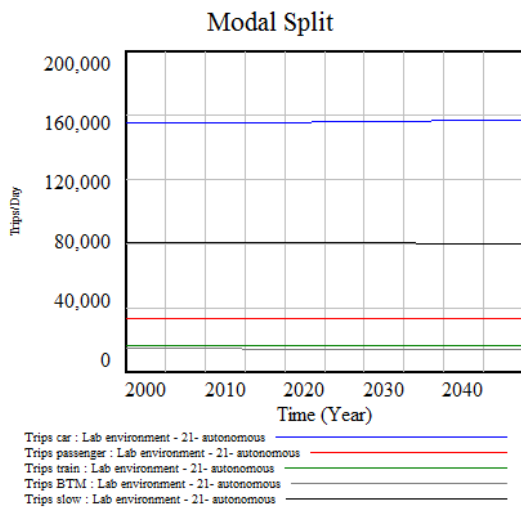
	2013	2050
Trips car	155300	157200 [1%]
Trips passenger	33360	33030 [-1%]
Trips train	16680	16440 [-1%]
Trips BTM	14440	14350 [-1%]
Trips slow	81070	79850 [-2%]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]

"Traffic loss hours in a peak (VOT corrected)"

Average speed on a relation

Speeds		Loss hours	
	2013		**2050**
Average speed in peak of a trip (car traffic)	41,07		40,76 [-1%]
Average speed on a relation	36,92		36,79 [0%]
% of car trips in the peak hours	0,4286		0,4285 [0%]
Loss hours in a peak (VOT corrected)	12380		12570 [2%]
Loss hours in a peak	82550		87020 [5%]

Relation 21 – Lab environment – Cooperative

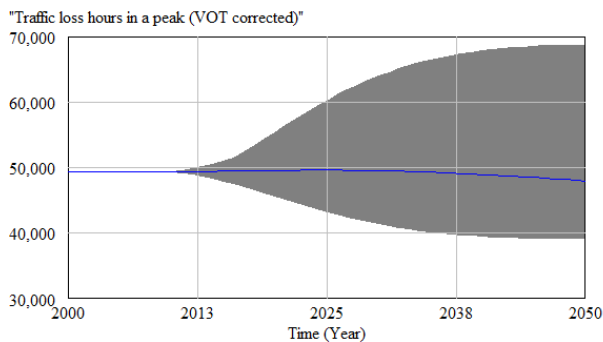| 1. Average speed of a trip by car (km/h)	2. Car trips in the peak hours[%]
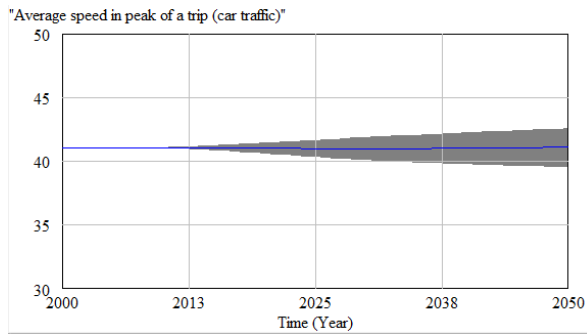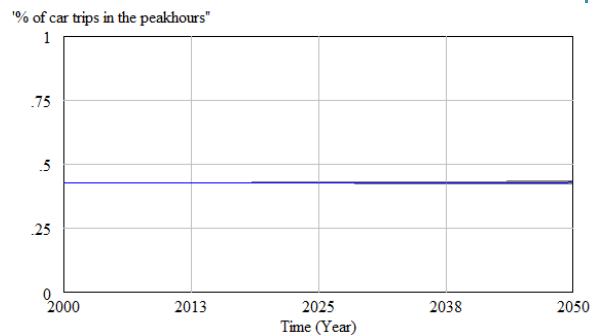


3. Modal split [# trips]
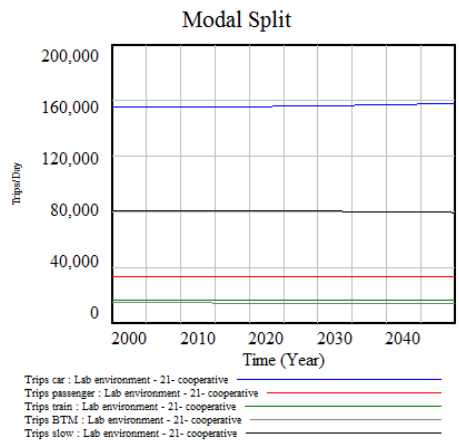
	2013	**2050**
Trips car	155300	157800 [2%]
Trips passenger	33360	32930 [-1%]
Trips train	16680	16360 [-2%]
Trips BTM	14440	14320 [-1%]
Trips slow	81070	79460 [-2%]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]

Speeds	Loss hours	
	2013	**2050**
Average speed in peak of a trip (car traffic)	41,07	41,11 [0%]
Average speed on a relation	36,92	37,06 [0%]
% of car trips in the peak hours	0,4286	0,4298 [0%]
Loss hours in a peak (VOT corrected)	12380	12090 [-2%]
Loss hours in a peak	82550	83690 [1%]

Relation 36 – Lab environment – Autonomous

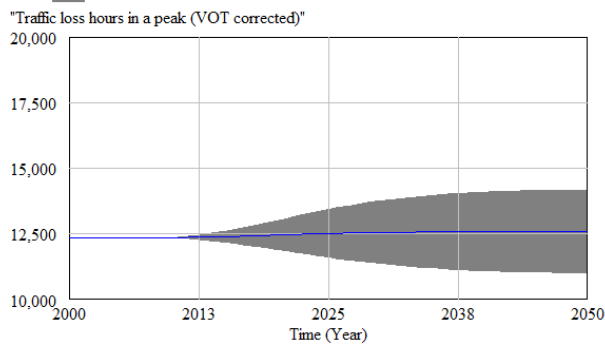| 1. Average speed of a trip by car (km/h)	2. Car trips in the peak hours[%]

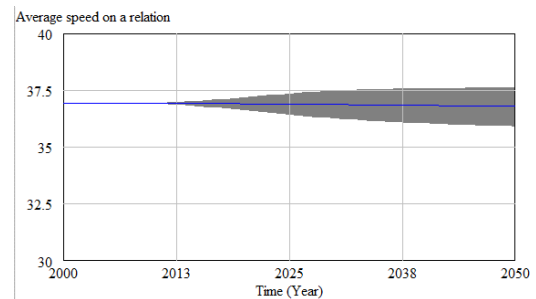
"Average speed in peak of a trip (car traffic)"
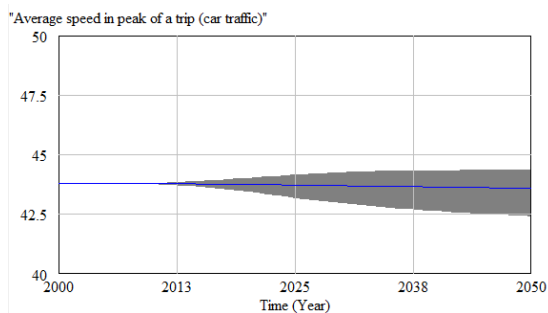
"% of car trips in the peakhours"
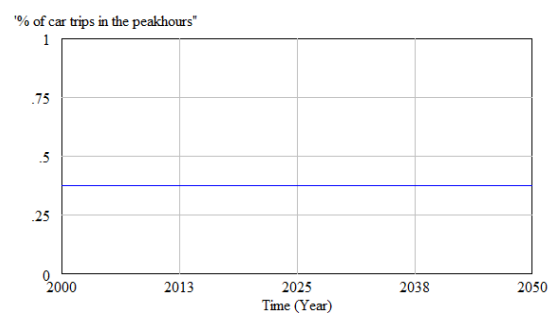
3. Modal split [# trips]			

Modal Split
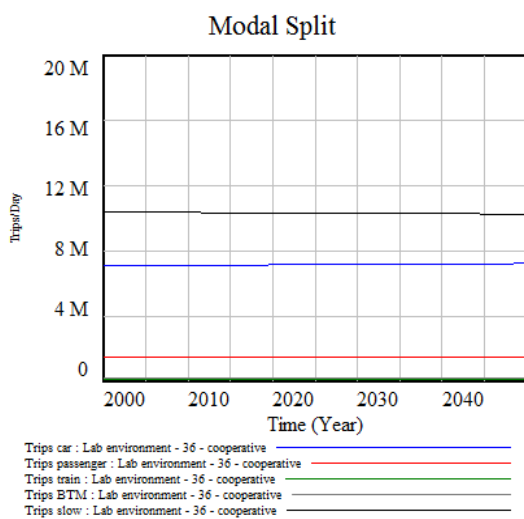
		2013	2050
Trips car		7131000	7232000 [1%]
Trips passenger		1519000	1515000 [0%]
Trips train		122200	121000 [-1%]
Trips BTM		219100	218100 [0%]
Trips slow		10360000	10270000 [-1%]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]
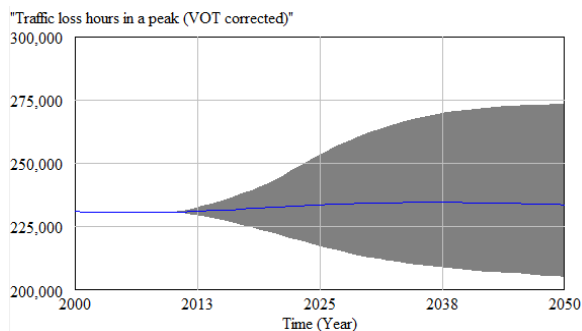
"Traffic loss hours in a peak (VOT corrected)"

Average speed on a relation
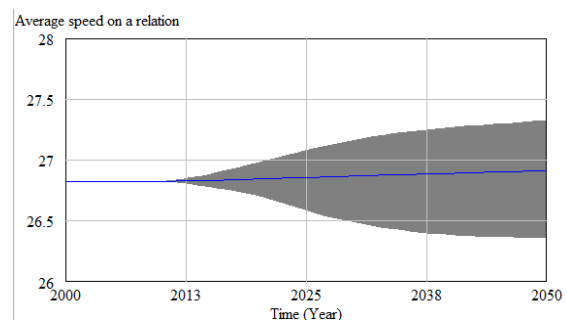
Speeds		Loss hours	
	2013		**2050**
Average speed in peak of a trip (car traffic)	43,78		43,59 [0%]
Average speed on a relation	26,83		26,91 [0%]
% of car trips in the peakhours	0,3757		0,3758 [0%]
Loss hours in a peak (VOT corrected)	231200		233700 [1%]
Loss hours in a peak	1541000		1618000 [5%]

Relation 36 – Lab environment – Cooperative

1. Average speed of a trip by car (km/h)	2. Car trips in the peak hours[%]

"Average speed in peak of a trip (car traffic)"

"% of car trips in the peakhours"

3. Modal split [# trips]

Modal Split

Trips car : Lab environment - 36 - cooperative
Trips passenger : Lab environment - 36 - cooperative
Trips train : Lab environment - 36 - cooperative
Trips BTM : Lab environment - 36 - cooperative
Trips slow : Lab environment - 36 - cooperative
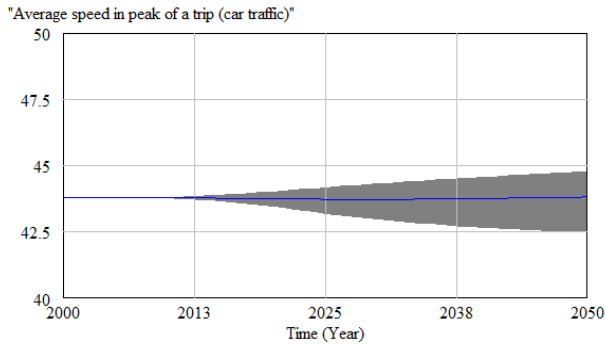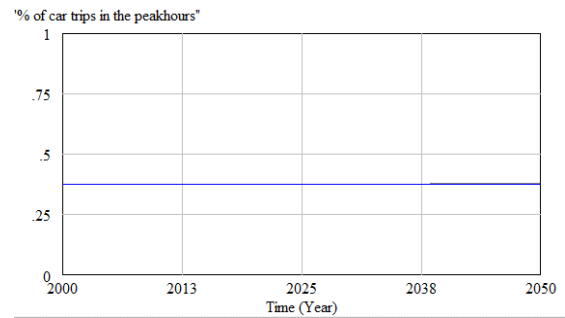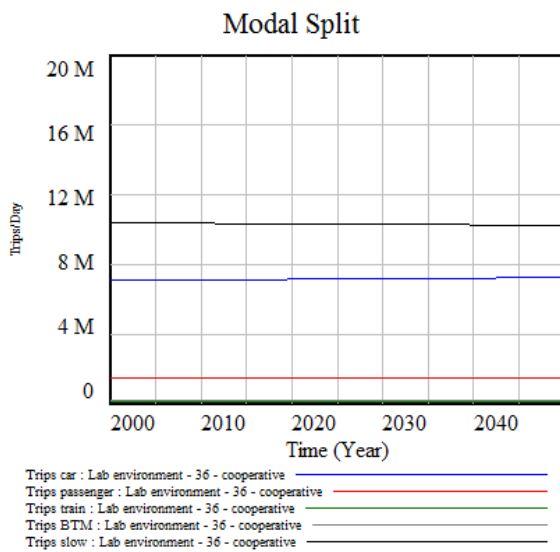
	2013	2050
Trips car	7132000	7258000 [2%]
Trips passenger	1519000	1513000 [0%]
Trips train	122200	120700 [-1%]
Trips BTM	219100	217800 [-1%]
Trips slow	10360000	10240000 [-1%]

4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]
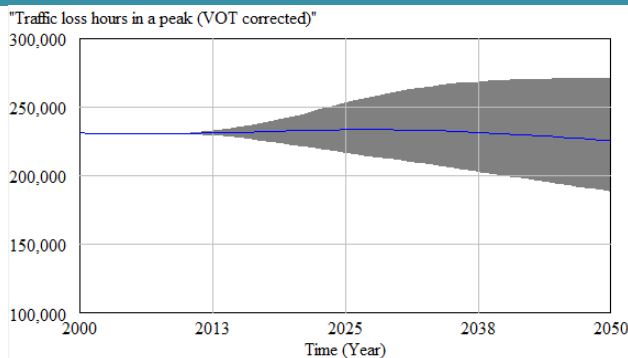
"Traffic loss hours in a peak (VOT corrected)"

Average speed on a relation
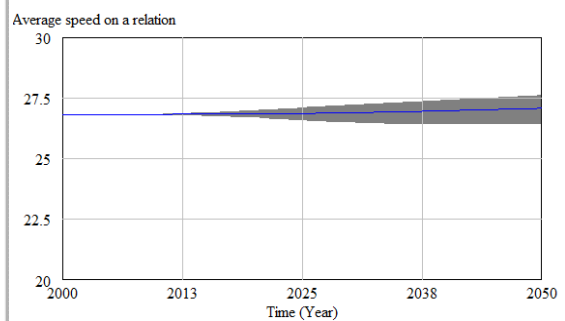
Speeds		Loss hours
	2013	**2050**
Average speed in peak of a trip (car traffic)	43,78	43,82 [0%]
Average speed on a relation	26,83	27,07 [1%]
% of car trips in the peakhours	0,3757	0,3762 [0%]
Loss hours in a peak (VOT corrected)	231200	225400 [-3%]
Loss hours in a peak	1542000	1560000 [1%]

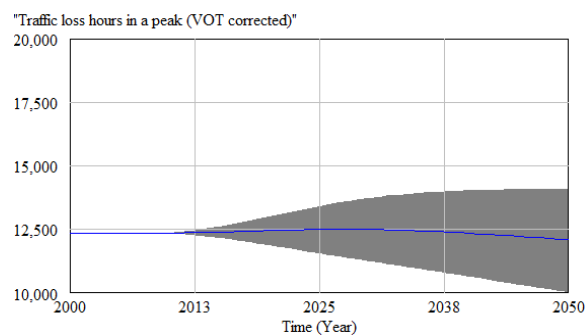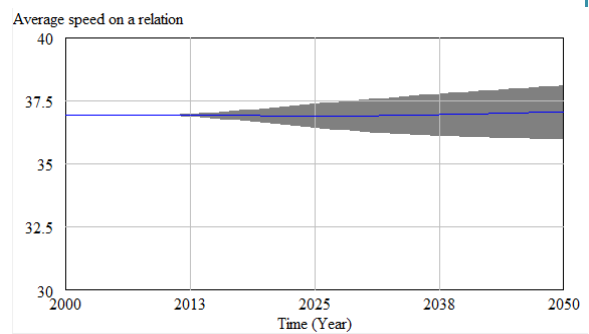## Relation 37 – Lab environment – Autonomous

1. Average speed of a trip by car (km/h)

"Average speed in peak of a trip (car traffic)"

2. Car trips in the peak hours[%]

"% of car trips in the peakhours"

3. Modal split [# trips]

Modal Split

Trips car : Lab environment - 37 - autonomous
Trips passenger : Lab environment - 37 - autonomous
Trips train : Lab environment - 37 - autonomous
Trips BTM : Lab environment - 37 - autonomous
Trips slow : Lab environment - 37 - autonomous

	2013	2050
Trips car	67510	71270 [6%]
Trips passenger	18910	18240 [-4%]
Trips train	87830	85130 [-3%]
Trips BTM	5480	5298 [-3%]
Trips slow	7726	7517 [-3%]

4. Loss hours corrected for value of time [€]

"Traffic loss hours in a peak (VOT corrected)"

4. Average speed on a relation [km/h]

Average speed on a relation

Speeds		Loss hours	
	2013		**2050**
Average speed in peak of a trip (car traffic)	52,55		50,99 [-3%]
Average speed on a relation	48,87		48,15 [-1%]
% of car trips in the peakhours	0,4989		0,4944 [-1%]
Loss hours in a peak (VOT corrected)	13300		14850 [12%]
Loss hours in a peak	88730		107600 [21%]

Relation 37 - Lab environment – Cooperative

1. Average speed of a trip by car (km/h)	2. Car trips in the peak hours[%]

"Average speed in peak of a trip (car traffic)"

"% of car trips in the peakhours"

3. Modal split [# trips]

Modal Split

Trips car : Lab environment - 37 - cooperative
Trips passenger : Lab environment - 37 - cooperative
Trips train : Lab environment - 37 - cooperative
Trips BTM : Lab environment - 37 - cooperative
Trips slow : Lab environment - 37 - cooperative

	2013	2050
Trips car	67510	73490 [9%]
Trips passenger	18910	17850 [-6%]
Trips train	87830	83550 [-5%]
Trips BTM	5480	5191 [-5%]
Trips slow	7726	7394 [-4%]

| 4. Loss hours corrected for value of time [€]	4. Average speed on a relation [km/h]
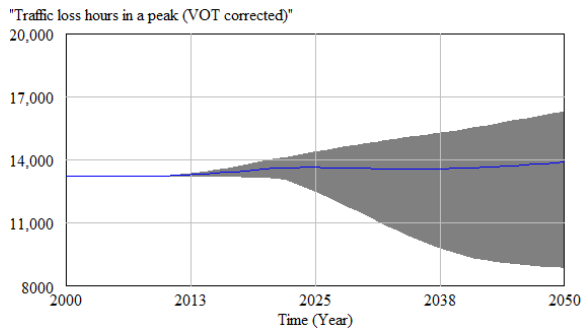
"Traffic loss hours in a peak (VOT corrected)"

Average speed on a relation
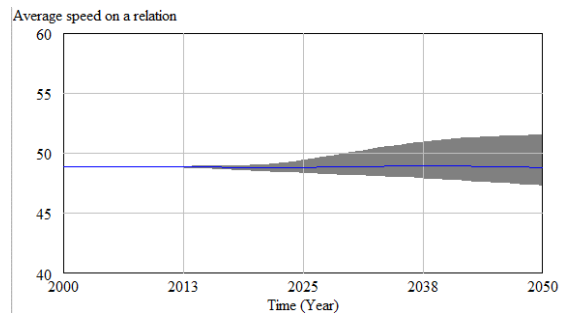
Speeds		Loss hours

	2013	2050
Average speed in peak of a trip (car traffic)	52,55	52,15 [-1%]
Average speed on a relation	48,87	48,81 [0%]
% of car trips in the peak hours	0,4989	0,501 [0%]
Loss hours in a peak (VOT corrected)	13300	13890 [4%]
Loss hours in a peak	88730	100900 [14%]

Relation 1 – Real world

1. Average speed of a trip by car (km/h)	4. Trips cars

Average speed in peak of a trip (car traffic)

"Average speed in peak of a trip (car traffic)" : Real world - 1 - no automated vehicles
"Average speed in peak of a trip (car traffic)" : Real world - 1 - cooperative
"Average speed in peak of a trip (car traffic)" : Real world - 1 - autonomous

Trips car

Trips car : Real world - 1 - no automated vehicles
Trips car : Real world - 1 - cooperative
Trips car : Real world - 1 - autonomous

2. Loss hours corrected for value of time [€]	5. Trips slow

Traffic loss hours in a peak (VOT corrected)

"Traffic loss hours in a peak (VOT corrected)" : Real world - 1 - no automated vehicles
"Traffic loss hours in a peak (VOT corrected)" : Real world - 1 - cooperative
"Traffic loss hours in a peak (VOT corrected)" : Real world - 1 - autonomous

Trips slow

Trips slow : Real world - 1 - no automated vehicles
Trips slow : Real world - 1 - cooperative
Trips slow : Real world - 1 - autonomous

3. Average speed on a relation [km/h]	6. Trips

Average speed on a relation

Average speed on a relation : Real world - 1 - no automated vehicles
Average speed on a relation : Real world - 1 - cooperative
Average speed on a relation : Real world - 1 - autonomous

Trips BTM

Trips BTM : Real world - 1 - no automated vehicles
Trips BTM : Real world - 1 - cooperative
Trips BTM : Real world - 1 - autonomous

Relation 21 – Real world

1. Average speed of a trip by car (km/h)

Average speed in peak of a trip (car traffic)

"Average speed in peak of a trip (car traffic)" : Real world - 21 - cooperative
"Average speed in peak of a trip (car traffic)" : Real world - 21 - no automated vehicles
"Average speed in peak of a trip (car traffic)" : Real world - 21 - automated

4. Trips cars

Trips car

Trips car : Real world - 21 - cooperative
Trips car : Real world - 21 - no automated vehicles
Trips car : Real world - 21 - automated

2. Loss hours corrected for value of time [€]

Traffic loss hours in a peak (VOT corrected)

"Traffic loss hours in a peak (VOT corrected)" : Real world - 21 - cooperative
"Traffic loss hours in a peak (VOT corrected)" : Real world - 21 - no automated vehicles
"Traffic loss hours in a peak (VOT corrected)" : Real world - 21 - automated

5. Trips slow

Trips slow

Trips slow : Real world - 21 - cooperative
Trips slow : Real world - 21 - no automated vehicles
Trips slow : Real world - 21 - automated

3. Average speed on a relation [km/h]

Average speed on a relation

Average speed on a relation : Real world - 21 - cooperative
Average speed on a relation : Real world - 21 - no automated vehicles
Average speed on a relation : Real world - 21 - automated

6. Trips train

Trips train

Trips train : Real world - 21 - cooperative
Trips train : Real world - 21 - no automated vehicles
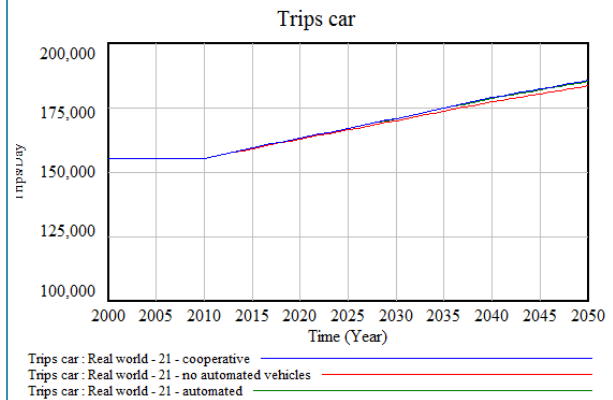Trips train : Real world - 21 - automated

Relation 36 – Real world

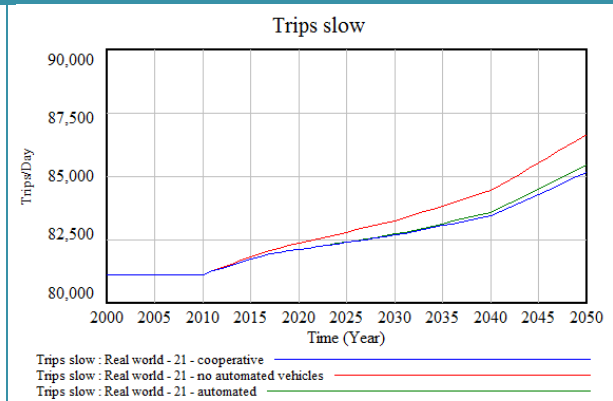| 1. Average speed of a trip by car (km/h)	4. Trips cars

Average speed in peak of a trip (car traffic)

Trips car

2. Loss hours corrected for value of time [€]	5. Trips slow

Traffic loss hours in a peak (VOT corrected)

Trips slow

3. Average speed on a relation [km/h]	6. Trips

Average speed on a relation

Trips passenger

Relation 37 can be seen in the main report.
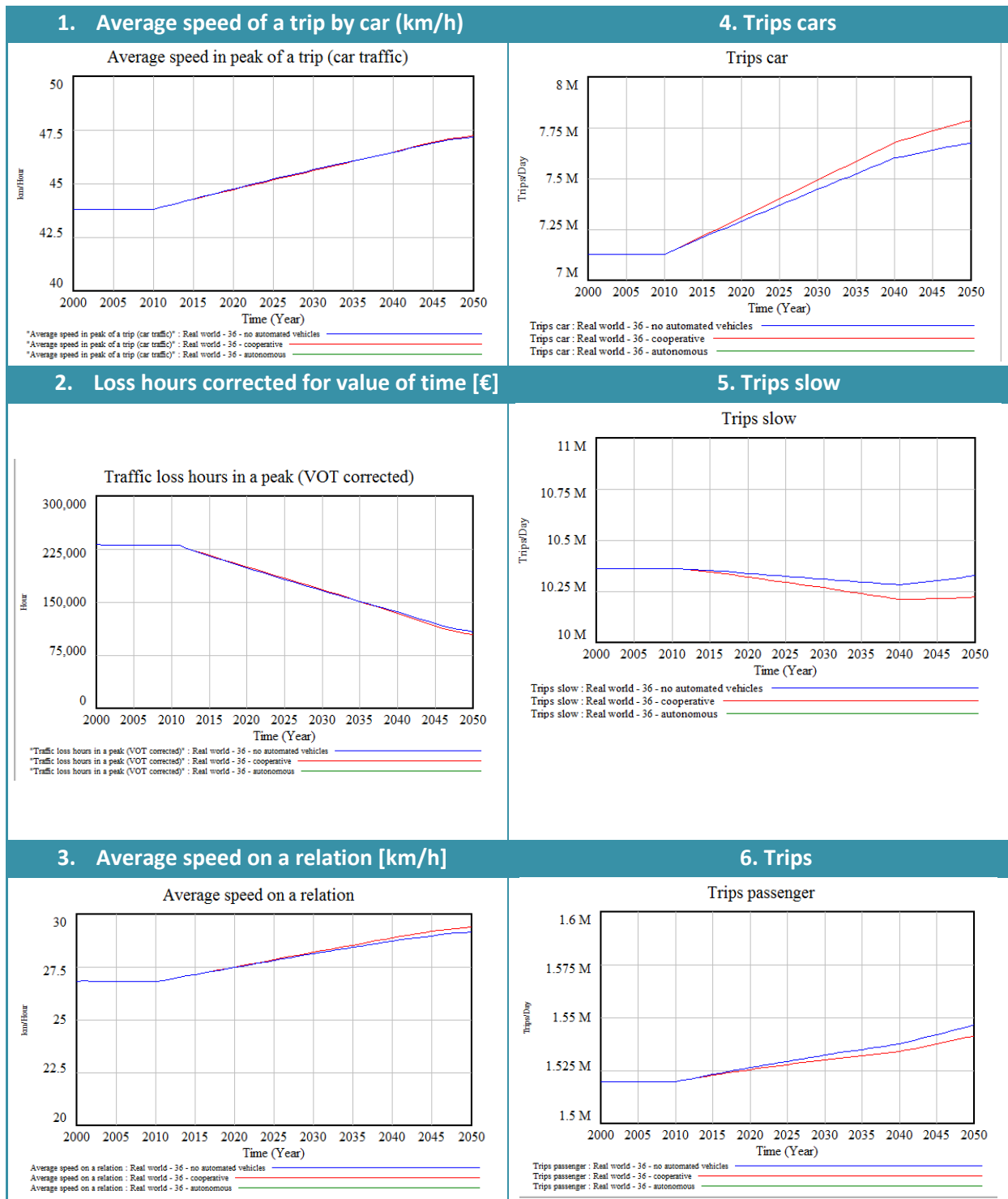
Appendix G: Improvements of the model

The model used for the research fits its purpose, but still can be updated with extra modules or be improved. The nature of a System Dynamics model is tried to be kept as a key value, so improvements which would lead to a totally different model structure are left out of this appendix.

Improvements

The SD-model certainly can be improved. In this section only improvements are mentioned which respect the explorative nature of the model. Aspects which change the nature of the model, for instance an explicit network, are not discussed as than explorative research becomes harder.

Two types of improvements are mentioned. Improvements on concepts which are already in the model, and extensions of the model to be able to simulate new features.

Recalibrate the mode and time of day choice
Almost all improvements on what is already in the model come down to recalibration of the time of day and mode choice. The way of calibrating and the use of OViN lead to a too sensitive mode choice and an too static time of day choice. For more detailed analysis the model should be recalibrated.

Not only the calibration data, but also the input data and of the model can be more accurate. Translating policy documents to inputs for the model is hard and roughly done in this study as the focus was on simulating the effects of automated vehicles and not of changes due to other factors.

More zone and relation types
The ScenarioExplorer (Heyma et al. 1999a) use besides the car ownership and geographical location more variables. Sex, income, age and trip purpose categories are present in the model. In 1999 this was quite hard to model, but recently Ventana (the software maker of Vensim) launched a beta version of Ventety, which is a software program which can handle many subscripts. With these subscripts the same model structure can be simulated for other categories. As the computation time of the model now is very low (100 runs in 1 second), the model can handle some extra subscripts.

Extensions

Longer trips made
One of the aspects the SD-model does not capture are longer trips made due to the automation of the fleet. Due to a lower value of time or a shorter travel time people might change houses or working locations. It is hard to model this into the model as than the trip generation has to be added. Another option is to add elasticities between the travel time, the value of time and the average distance driven.

There are two complicating factors in this effect. The first is that the relations are not described in literature, so assumptions have to be made. Complicating factor number two is that due to a longer distance also more 'capacity is consumed', so more congestion can arise. So, not only the travelled distance should be updated, but also the intensity of the trips.

Time depended impact factor

At this moment the PCU for automation is depended on the penetration rate. However, as technology gets more mature over time the PCU can also be time depended. In 2020 the PCU value can be 0,9 for 80% level 3 vehicles, whereas in 2030 this can be 0,7 due to new vehicles or software updates. Still penetration rate might be the same. If this is done a 3D function for the PCU has to be constructed.
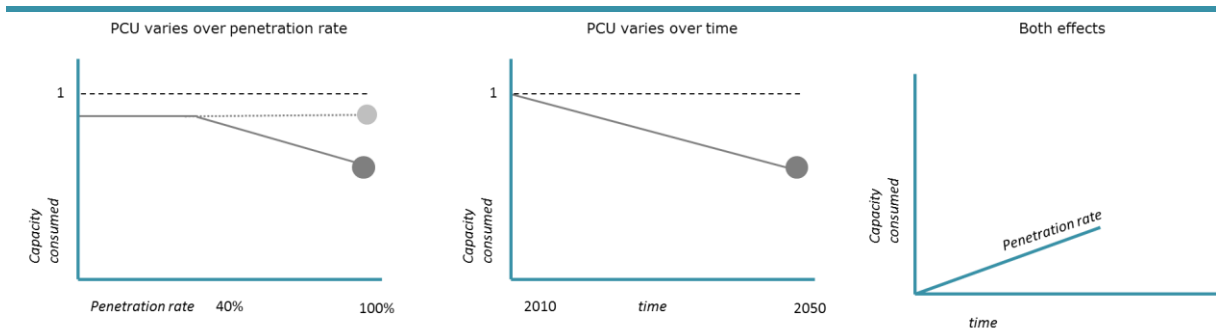

figure 2: in the left figure the PCU graph used in this research. This can be combined with a PCU function which differs over time (middle) to a 3D function which takes both into account (right).

CO2 and other environmental aspects

With traffic data also emission figures can be calculated. The model discussed in this paper can also easily be extended with a CO2 module. For this extension all the amount of kilometres driven in free flow and in congestion are needed, plus the emissions for both states. A separation can be made for trucks and normal cars. The yearly figures from the Ministry of Infrastructure and Environment can be used for the CO2 emissions per driven kilometre. The same can be done for NO_x or other greenhouse gasses.

Safety

Just as CO2 can the model also be used to aggregately calculate how safety will be influenced. If there are predictions for the amount of traffic accidents per level of automation per road type, a safety module can be constructed. Automation probably will have a positive effect on safety, but due to more kilometres driven this might have to be adjusted downwards.

Combine with a car ownership model

The model of Nieuwenhuijsen (2015) is now used as input for this model. What is not modelled is that there is probably feedback between the average travel time per mode and the adoption rates. By combining the models such a feedback loop can be modelled.

Parking model

The ScenarioExplorer (Heyma et al. 1999a) makes use of a parking model. Based upon the attractiveness of a zone the time to find a parking place increases or decreases. Searching of parking spots is left out of this model, but can be added to a new version. In this extension can also be taken into account that level 4 and 5 cars are able to find themselves a parking spot.

Split the assignment up in different parts of the trip

The assignment now consists of one speed-flow curve. However, different parts of the trip can be calculated based upon different speed-flow curves. In **figure 3** an example is given. The total travel time is the sum of all individual travel times.

Effects of automated vehicles can be divided per road class. In cities the effect of traffic lights can be added, on ring roads only a few capacity effects arise, and on the straight highways many effects arise. Building the model like this makes it easier to use microscopic literature and makes the model more explainable to non-experts. In this way the effects of automated vehicles can more detailed be researched, without an explicit network. Also the overlap factor can be calculated more accurate.

figure 3: an example of different speed flow curves to calculate the travel time between large cities in the Randstad.

Assignment with more inputs than just the capacity

As is shown in figure 3, the calculation of the average speed can be done based upon multiple speed-flow curves. In inner-city situations the road capacity might not be the most important parameter to calculate the speed with. For inner-city traffic a constant travel time can be chosen, with penalties for the amount of traffic lights.

Add level 4 and 5 to the model

This model is made for level 0 till 3. Adding level 4 and 5 as extra modes in the current model is not complicated, but simulating their effects correct will need a lot of extra extensions and feedback loops. Here a short summary of what need to be changed to model level 4 and 5.

Spatial effects	A spatial relation between zones as automation of level 4 and 5 can have significant effects on where people work and live. This would need a large change to the model as now zones are simulated in depended, but in this case need to be simulated simultaneous. The spatial effects can be given exogenous, but this is too unsophisticated as there is a feedback loop between the speeds on the road and the spatial component.
Trip generation and distribution	As level 5 can create whole new travel patterns arise. Elderly, disabled or children can make use of a car without another driver. Due to totally new patterns, the choices of generation and distribution should be modelled, instead of extrapolating it.
Simulating not only people, but also vehicles	As empty trips can be made, and sharing of vehicles for a trips gets more easy the amount of people in a vehicle can variate strongly. Therefore it is advised to not only simulate the people making choices, but also the vehicles they use.
Kilometres driven variable	In the current model the amount of kilometres driven is set constant. Already with level 4 and 5 automation longer trips can be made. This happens when the trip distribution is changed.

Appendices Communication (part B)

Appendix H: Set-up of the interview

Here an example is shown of the interview with the manufacturer. The other interviews have the same set-up, but slightly different questions.

Introduction
- Explanation interview: "This whole interview is about self-driving vehicles on the public roads. During the whole interview you may assume you have the role of the manufacturer of the car. The interview is about how you think of automated vehicles."
- Planning: : "the interview consists of a few questions and a small creative assignment. It will take about 30 minutes."
- Can I record the interview?

Questions
- Can you introduce yourself?
- "What was the reason for you to start developing automated vehicles?"
- "How do you see driving in 10 years from now?"
- Explanation level 3: "It is expected that within a the coming decades a self-driving car is available on the market for consumers. My research is about the level 3 car: this car has taken over most of the driving tasks. However, you still need a driving license, because if the car is a difficult situation, you need to be able to take over the wheel. So you are able to read a newspaper, but if the car warns you to take over, you need to drive yourself."
- Check if this is understood
- "Do you get exited from this level of development? Which sides?"
- "Are you afraid of some aspects?"

Creative
- Explanation: "Imagine, the self-driving car is available in store. With this car comes a flyer, the flyer says what the car is capable of. The question is to design your ideal flyer. So, the ideal flyer of you as manufacturers. In this flyer you don't have to take opinions of other actors into account. You don't need to give technical features, only values like: 'it's safer than a human' or 'improves traffic flows'."
- With the designing comes a helping kit.
- "Can you explain the flyer?" Maybe, some questions to clarify
- After the flyer
    - Cooperative or autonomous path is defined in literature, what is your favorite?
    - Communication is closed around automotive industry, how come?
    - "Image, the car is safe, but does not improve traffic flow, do you bring it on the market?"
    - "Imagine, the car has lots of comfort, but is not safe, do you bring it on the market?"

Appendix I: Transcripts of the interviews

Interview ANWB

A: Member ITS team ANWB 1, B: Member ITS team ANWB 2

S: Steven Puylaert (interviewer)

10:05, 8 juni 2015

Inleiding

S: Het interview bestaat voor een deel uit vragen en een deel uit een creatieve opdracht. Ik ben benieuwd hoe dat met z'n tweeën gaat. Het geheel duurt denk ik een half uurtje. Het gaat over zelfrijdende auto's op de openbare weg.

A: Heb je een definitie van zelfrijdend. Compleet zelfrijdend, alles erop en eraan?

S: Eerst ben ik in alles geïnteresseerd, en daarna, zeg maar, in level 3. Dat zegt jullie wat?

A+B: Ja.

S: Level 3 gaat mijn onderzoek over.

A+B: Okee. A: prima.

Vragen

S: Jullie zijn het ITS team van de ANWB, wat zijn jullie verantwoordelijkheden?

A: [B], vertel maar

B: Wat wij doen is, kijk wij zitten op algemeen ledenbelang. Wij zijn bezig met het belang van de leden in de gaten houden. Meestal weten we wat leden willen, maar dat is met ITS anders. Veel leden weten niet wat de systemen kunnen. Maar we zien dit erop afkomen. Dus we vinden het heel belangrijk om ons erin te verdiepen. Niet alleen voor onze leden, maar voor onze eigen business ook. Betekend nog al wat voor de wegenwacht. Als ze zelf registeren wanneer ze pech krijgen. Dus, wij zijn heir mee bezig om grip te krijgen op de nieuwe ontwikkeling en eventueel adviezen mee te geven aan fabrikanten. Bijvoorbeeld vanuit Human factors.

S: Hebben jullie veel contact met fabrikanten

A: Ja, en niet met allen. We hebben een zakelijke markt, daar hebben we een x aantal fabrikanten waar we contracten mee hebben afgesloten. En daarnaast hebben we vanuit verenigingsperspectief wel eens contact hebben. Over de human factors vooral. Het valt wel mee, als het om dit onderwerp gaat. Fabrikanten zijn zelfstandig aan het ontwikkelen. Het is een te vroeg stadium om hun ontwikkelingen te delen.

B: Wat wij wel hebben is contact met heel veel andere actoren in het veld. Wij zijn aangesloten bij DITCHM. Wij komen bij Connekt. Zo zijn wij bij een aantal van die overlegstructuren. Zijn we betrokken.

S: Wat is nu jullie beeld van de zelfrijdende auto.

A: Heb je een termijn die je daar aan koppelt

S: De komende 10 jaar

A: Ik denk dan dat wel level 3 al veel auto's hebben rijden. Ik denk juist ook dat level 3 wel heel veel vraagtekens met zich mee brengt.

S: En wat zien jullie als de ANWB in het geheel van al die actoren?

S: En, wat wil de ANWB doen om dat proces te helpen?

B: Informeren naar onze leden. Maar ook naar de industrie. Let erop dat je de gebruiker meeneemt in het geheel. Dat je niet, wat nu gebeurd, dat elke fabrikant zijn eigen systemen ontwikkeld. En vervolgens stap je in een auto en dan is het net een computer waar je toch weer moet wennen. Waar is dit knopje voor? Dat is bij elke auto weer anders. Op een bepaald moment moet je ook communiceren met andere auto's. Als elke fabrikant een eigen auto ontwikkeld kan dat fout gaan. Dat is nog niet top of mind bij die fabrikanten. Werk samen, dat proberen we ook tussen de oren te krijgen. Trek samen op. Dat is de sleutel tot succes.

A: Wij zijn een vereniging, maar ook een consumentenorganisatie. Wij komen op voor de belangen van de leden / onze consumenten. In dit geval voor alle autoberijders. Hierin zitten we in een ontwikkeling van ontwikkeling en connecten hoe je het ook noemt, de wetenschap is bezig, bedrijfsleven om een verdienmodel erin te zien. Maar ze doen het redelijk eigenstandig. Ze hebben alleen iets te weinig oog voor de gebruiker, die hem gaat kopen. Die moet het gaat accepteren. Die moet centjes ervoor neer willen leggen. Dus ja, dat is met die mindset moet je naar de ontwikkeling kijken. Op basis van technologie gaat het echt wel lukken.

S: En, uhhm, jullie hebben het over gebruiker van de zelfrijdende auto, maar hoe kijk je aan tegen de mensen die niet in de auto zitten? Nemen jullie die ook mee?

A: Alle weggebruikers. En de interactie die maakt het interessant. En spannend. Het is inderdaad dat je een transitieperiode krijgt die best wel lang kan duren. Je hebt de old school auto, en een level 2 en veel level 3 en wat level 4 en voetgangers en fietsers, en hoe interacteert dat met elkaar. De kans op veiligheid is best hoog, maar het pand er naar toe vraagt wel een aantal… hoe we ten aanzien van verkeersveiligheid naar kijken.

B: Dan heb je dat binnen en buiten de bebouwde kom. De voorbeelden van [A] is binnen, maar de snelweg. Ja daar rijden auto's heel dicht op elkaar. Moet je de linker strook vrij maken.

A: Motorrijders, in- en uitvoegen. Ja. Het is.. We kijken nu heel positief tegen de ontwikkelingen, verkeersveiligheid is belangrijke. Maar ook doorstroom. Misschien wel goedkoper. Zuiniger rijden. Maar er zijn wel een aantal vraagstukken, en alleen dat eindbeeld, waar je veel mensen over hoort. Over 5 jaar of over 10 jaar, zitten we allemaal en masse te computeren achter het stuur. Ik mag het hopen, maar we zijn er nog lang niet.

A: Beetje inslaap vallen. Knikkenbollen. Er gaat allerlei

B: Informeren. Onze leden informeren. Leden meenemen. Ja, wij zijn aan het kijken hoe we dat kunnen doen. Hebben we in het verleden ook met elektrisch gedaan. Proefrit door heel NL. Echt kennis laten maken. Op voorwaarde dat je dan ook met 30 man proefrit ermee gaat maken. Misschien zoiets. Wij zijn er nog niet helemaal over uit. Dit is een beginfase. Maar ook bij alle nieuwe ITS systemen. We hebben een I-mobility dag gehad. Dat was B2B, maar daar zijn een aantal leden bij uitgenodigd om de moderne technieken te testen. Dat zijn dingen waar we eventueel over na kunnen denken.

S: ja. Ja. En, jullie weten wat level 3 is. Je zit in de auto en je kan computeren of de krant lezen. En als tie gaat piepen moet je m weer overnemen. Waar worden jullie enthousiast van als je zo'n beeld hoort.

B: Je zegt nu 2 dingen. Level 3, en als je een beeld hoort.

S: Nee, waar wordt je van level 3 enthousiast

B: Nou, van level 3 worden wij niet zo enthousiast. Je kan computeren en als je een piepje hoort moet je het overnemen. Je hebt dan een omschakelingsperiode en de vraag is of die periode om weer te wennen aan dat stuur niet te lang duurt.

A: Dat je een schrikreactie hebt. Doe je juist iets geks. Ga je ineens op de rem staan. Dus juist technologisch gezien is het leuk bedacht, maar hoe interacteert dat met het menselijk handelen, en de gevaren. Is de een vaardiger dan de ander. Niet iedereen reageert altijd hetzelfde. En hoeveel ervaring moet je krijgen.

B: Wij zitten er ook mee te stoeien. Moet je niet van level 2 naar 4 willen. En daar zijn wij zelf ook nog niet over uit.

A: Ik merk wel dat er steeds meer organisaties roepen dat level 3 misschien niet goed is. Het klinkt goed, leuk bedacht, maar niet realistisch. Nu merk je ook steeds dat er meer onderzoek naar human factors is. Hoe interacteert dat met menselijk handelen. Omdat het in kinderschoenen staat. Technologie is misschien al ver, maar hoeveel mensen hebben nu ITS systemen. Wie heeft er langere tijd ervaring mee, das een heel klein groepje. Daar moet studie naar gedaan worden. Daar denk ik dat het bewijs daar gaat zijn dat level 3, nou, mwah. B: beter overslaan.

S: Jullie zijn vooral bang van level 3. Maar zijn er ook dingen..

A: .. ik weet niet of wij bang zijn, wij zijn vooral realistisch. Je ziet wat de reactie tijd is, en alle auto's anders zijn uitgerust. Mensen hebben er ervaring mee. Je hoort nu wel mensen die juist een luxere auto hebben, die gek worden van de piepjes, en niet weten wat ze moeten doen, hij reageert anders dan verwacht. Dan denk ik als, als er meerdere maten wordt toegepast, bij een grotere groep, dat oudere mensen als jongere, minder ervaren mensen, in moeten grijpen, dat lijkt mij als dat met je gezonden boeren verstand, dat dat best nog wel tot onveilige situaties kan leiden.

B: Je hebt die level 3 situatie, kijk, het is niet dat je kan computeren achter het stuur, bij level 4 kun je lekker met de Ipad mails kijken. Alleen bij level 3, ja als mensen niets doen, dan gaan ze toch een beetje inkakken. Ze moeten toch wel wat, en het is nu al met social media achter het stuur. Dat ga je dan ook krijgen.

B: Garantie van da fabrikant is in ieder geval nog van de

gedrag ontstaan wat niet goed is op dat level 3 om dat over te kunnen nemen. Ook op lange ritten. Dat is waar ons zorgen om maken.

S: Jullie zijn niet de enige hierin, bij RWS werd er ook gezegd, wij eisen garanties van level 4.

A: Ja, sla het of over of, ja, wij weten niet precies hoe het is, wees er kritisch op. Het gaat niet zo geleidelijk.

B: Het is een beetje raar, dan eisen we garanties van level 4, dan zeg je eigenlijk dat je level 3 niet wilt. Dat is dus hetzelfde als wij net zeggen. Volgens mij moet je gewoon level 3 overslaan. Als je garanties eist, heb je level 4.

A: Heb je mensen gesproken die wel enthousiast zijn?

S: Veel consumenten denk dat wel.

B: Ja, daar zit dus ons stukje verantwoordelijkheid in om dat goed voor te lichten

A: Ik kan het mij ook wel voorstellen, het is wel relaxed. Een soort cruisecontrol. Niet schakelen.

B: Dat zelf rijden klinkt heel interessant, maar als ze echt door hebben wat het voor hen betekend, en voor de veiligheid. Dat ze dan toch zeggen: we willen verder. Want eigenlijk wil je gewoon zelfrijdend.

A: Nog 1 vraag. Hoe heb je de consument gesproken

S: Tot nu toe nog op dezelfde manier als jullie. Maar er komt nog een soort enquête. Ja.

Creatieve gedeelte

Uhhm. Het creatieve deel. Uhhm. Stel de zelfrijdende auto van level 3, toch, die komt in de winkel. Of eventueel mag het ook wel level 4 zijn. Bij de auto zit een brochure, over wat hij kan en wat hij doet. En de vraag is om jullie ideale brochure van de zelfrijdende auto te ontwerpen. Dus hoe jullie het liefst zien. Daar zijn een paar hulpdingen bij. Dan hoef je niet helemaal from scratch beginnen. Leg ik hem netjes in het midden neer.

B: Hoe creatief ben ik.

S: Er staan vooral opstapjes op het blad. Kijk wat je wilt gebruiken. Je mag het overschrijven. Er staan vooral opstapjes op.

A: je wilt vooral dat we vooral over de garanties praten.

B: Dat is vooral waar wij iets over willen weten

A: Het zou fantastisch mooi zijn als dit letterlijk op 1 A4tje zou kunnen. Als de brochure of gebruiksaanwijzing daarop past. In jip en janneke taal. Hoe minder tekst erop, hoe duidelijker het voor de consument is. Eindeloze lappen tekst met randvoorwaarden daar heeft niemand iets aan. Ik vind deze dus nu al mooi.

B: Nu maken.

A: Ik ben niet creatief. Ik denk dat we gewoon….
      Je bedoelt echt de brochure van wat kan die.

S: Ja de reclame, volgens jullie. Niet de gebruiksaanwijzing, meer de …

B: Hoe verkoop je m?

S: Vanuit jullie ideale .... dan.

B: Hoe wij hem het liefste willen zien vanuit de fabrikant.

S: ja!

B: In ieder geval wat je beloofd, en duidelijk wat de garanties zijn. Wij willen duidelijkheid naar onze leden.

A: De data vind ik ook heel erg belangrijk. Hij genereert heel veel data.

A: Het moet voor alle gebruikers van de weg

bestuurder. A: of de berijder, want wie heeft de auto nog. B: u bent eigenaar van de voertuigdata.

A: Je kan ook niet echt van bezit spreken, maar dat begrijp je wel.

B: De garanties moeten er nog bij, dat je weet waar je het over hebt.

A: Ik vind het best lastig. Wat kan die??
Level 4 doen we dan. Alleen in uiterste noodzaak moet je zelf ingrijpen. Met voldoende reactietijd. Het kan ook zo zijn dat de auto in ieder geval garandeert dat hij naar de vluchtstrook gaat. Ik ben disconnected. Denk even mee, dan gaan we weer

B: Dat doen ze bij Volvo nu ook, bij de test in Gotenburg. Hij gaat in een traject van 50 km om de stad rijden. Als hij buiten de geplande trajectzone komt wijkt hij uit op een speciale uitwijkstrook. Zodat de auto daar tot stoppen komt.

A: Aansprakelijkheid… Ja. .. ja het moet duidelijk uitgelegd worden. Alle elektronica

B: U krijgt: een introductiecursus
Al die bediening die anders is. Bij de huidige auto's zou dat eigenlijk al moeten. Sommige doen dat ook via ANWB. Test en trainingscentrum hebben wij daarvoor. En de ANWB drivers academy heet dat tegenwoordig.

Vragen

S: En doorstroming? Moeten daar garanties over gegeven worden?

B: Je kan geen garanties bieden, maar je biedt wel meer kans op doorstroming als er meerdere level 4 auto's rondrijden.

S: Stel de auto's houden altijd star 2 sec afstand, wat meer is dan nu in de spits gebruikelijk is

B: Dat wordt te groot

S: Dat zou negatief zijn voor de doorstroming, zouden jullie dat accepteren?

B: Dan krijg je ook een andere inrichting. Als ik helemaal naar de stip op de horizon kijkt, dan heb je geen OV meer. Waarom willen mensen nu een auto voor de deur? Als ze weg willen kunnen ze gewoon weg. Als je met 1 druk op de knop een auto voor je deur hebt staan, hoef je er geen meer te bezitten.

A: Überhaupt aanschaf zal omlaag gaan denk ik. Naar aanleiding van je behoefte krijg je een kleine of een grote auto.
Dus de brochure is misschien wat outdated voor de consument. Je koopt een mobiliteitsconcept. Je krijgt soms een fiets, soms een auto. 24/7 mobiel. Meer een concept, dan 1 type auto. Of 1 merk. De een wil luxe, de ander vooral goedkoop.

B: Of op vakantie een grotere auto voor je koffers. Dus misschien krijg je eerder mobiliteitsconcepten.

A: Denk dat wat ik nu mondeling heb toegelicht, dat je dat in je brochure kan opnemen.

S: Maar ik stelde de vraag over doorstroming. Stel de auto zorgt voor een iets lagere doorstroming, en misschien wel andere voordelen voor de gebruiker. En daardoor minder voor de autorijders zonder slimme auto. Wat vinden jullie daarvan?

aantrekkelijker worden. Voor iedereen moet het beter worden. De files moeten gewoon weg. We zullen nooit een voertuig voortrekken. Daar is de ANWB zeker tegen. Voor het hele concept moet het beter worden. Voor alle gebruikers moet het voordelen met zich meenemen, of in ieder geval niet benadelen. Het kan niet zo zijn dat er 2 stroken zijn waar level 4 doorrijden waar de rest nog in de file staat op 1 strook.

S: En accepteren jullie een kleine periode van onveiligheid, om daarna grotere veiligheid te kunnen krijgen?

B: Er gaan ongelukken gebeuren. Je hebt nu al berichten van google over aanrijdingen, al blijkt het dan om andere mensen te gaan. Je zal door de ongelukkenfase heen moeten. Hoe ernstig gaan die ongelukken worden en wordt het dan niet door de consument afgeschoten. Dat is een risico. Zeker met verschillende merken die hun eigen systemen maken. Of als het geen ongeluk is, dan vertraging. Dat ze allemaal stoppen.

S: En dat is niet erg?

A: Dat is wel erg, maar ik heb geen antwoord, hoeveel doden er extra mogen zijn. Ik vind misschien wel 0. Maar je moet kunnen aantonen dat het met een normale auto ook zou gebeuren. Je kan niet met mensenlevens gaan testen.

B: Je hebt consumentenvertrouwen nodig. En als hij het gevoel heeft een proefkonijn te zijn dan stapt hij er niet in.

A: Een minder veilige periode ga ik niet accepteren.

B: We gaan niet de mens als proefkonijn zien. Je weet dat het gaat komen, je moet het uit kunnen leggen, dan is het te accepteren. Maar als het voertuig voor meer ongelukken zorgt, dan is het einde oefening voor het zelfrijdende auto principe.

S: Wat vinden jullie van de rol die de overheid nu inneemt?

A: Goed dat ze zo positief zijn. Nu zijn er vooral nog kleine initiatieven, maar de grote autofabrikanten moeten hier ook komen testen.

B: De overheid moet wel beseffen dat er altijd een rol voor hun overblijft. Een regierol over het verkeersbeeld, dat moet bij de overheid blijven liggen.

S: Zouden jullie die regierol sterker willen zien?

B: Dat is nog niet te zien. A: Erg lastig te bepalen

S: Maar zouden jullie dat willen?

A: Als ik het niet zie kan ik het niet bepalen. Maar misschien krijgen ze die behoefte. Dat ze de markt willen sturen.

B: Of gaan de systemen zelf sturen. Dat ze zelf een alternatieve route.

A: Er zal altijd een verkeerstoren moeten zijn.

S: Het kan natuurlijk zijn dat linksom de ring van Rotterdam voor jou sneller is, maar dat je daardoor andere zo erg vertraagd, dat voor het systeem de andere kant op sneller is.

A: Tsja, dan betaal je maar een euro extra.

S: Rekeningrijden.

A: Dat woord zou ik niet gebruiken, maar betalen naar gebruik.

B: Dat ga je sowieso krijgen. Zeker als de auto niet van jou is.

Interview Consumer
C: Consumer
S: Steven Puylaert (interviewer)

Inleiding

S: uhh. Heb jij een rijbewijs?

C: Ja.

S: Rijdt jij veel?

C: Mmm, nee, niet heel veel.

S: Hoeveel ongeveer?

C: Een keer per twee, drie maanden. En dan heel af en toe een zomer echt heel lang op vakantie.

S: Je hebt geen eigen auto

C: Nee

S: En, wat vind jij de grootste problemen op de weg

C: De grootste problemen op de weg? Als in het algemeen of voor mij?

S: Voor jou?

C: Voor mij, het grootste probleem…. Is…. Jaaa.. Ik heb niet zoveel problemen. Als ik rij, als ik rij, dan zijn dat korte stukjes. Even heen en weer. En op vakantie, nergens echt last van, altijd wel gezellig.

S: Misschien heb je wel gehoord dat het de verwachting is dat binnen een aantal jaar zelfrijdend auto's op de markt komen. Die nemen dan een deel van de rijtaak over. En, de zelfrijdende auto's komen in verschillende levels. Je zou nu cruise control in de auto al een soort van zelfrijdende auto kunnen noemen. Het einddoel is een auto zonder stuur. Mijn onderzoek gaat over auto's die in level 3 zitten. Dus dat is hier tussenin. Dan gaat de auto een deel van de rijtaak overnemen. Maar als hij begint te piepen moet je nog steeds het stuur overnemen. Het lijkt dus nog steeds op een gewone auto, maar dan neemt hij een deel van de taken over. Als chauffeur moet je nog steeds wel een rijbewijs over hebben en lastige

taken uit zoals je nu ook doet.

S: Ja, dus niet dronken achter het stuur, of je kinderen laten rijden. Je moet nog steeds een rijbewijs hebben.

Vragen

    Wordt je hier enthousiast van?

C: JA! Zeker! Een beetje rijden op vakantie is leuk, maar voor woon werkverkeer snap ik echt wel dat dat geen pretje is. Geen lol is om elke dag te rijden. Dat als je dan een beetje kan ontspannen tijdens het rijden. Je hoeft dan niet echt op te letten tijdens het rijden, alleen als tie piept.

S: Ja. Dus vooral ontstpanning. Nog andere dingen?

C: Uhhm.. Nou ja, voor mij eigenlijk vooral beetje ontspanning. Ja. Ik kan wel dingen verzinnen voor maatschappelijk enzo. Minder ongelukken. Maar voor mijzelf zou het echt zijn dat je naar je werk kan zonder dat je echt moet opletten en zo.

S: En ben je ergens bang voor als je dit idee hoort?

C: Uhhm. Nee eigenlijk niet. Ik heb er wel erg vertrouwen in. Dat de techniek het beter gaat doen dan de mensen. Dat lees je ook heel veel. ZA kunnen veel beter rijden dan dat mensen kunnen. Dus hoe meer ZA, hoe veiliger het wordt. Als het haalbaar is koop ik er wel een. Lijkt me wel top.

Creatief

S: Stel, de zelfrijdende auto die ik net heb beschreven komt in de winkel te liggen. Bij elke auto zit een brochure of een flyer. Dit is het creatieve gedeelte van het interview. Ik heb hier een soort van

situaties, sneeuw, regen, wegwerkzaamheden zegt hij tegen je dat je zelf weer moet rijden. Snap je een beetje wat ik uitleg?

C: Dus als tie normaal gesproken rijdt tie volledig zelf. Volledig autonoom, en bij piepen moet je overnemen, en voer jij alle

C: Ah, jeetje. PFff. Okee.

S: Ik zal even geen vragen stellen, kun je gewoon even je gang gaan.

C: Oh wauw. Das een tijd geleden. Knutselen.
Garanties van de fabrikant, das een goeie.
Ik kan niet tekenen, dus ik ga gewoon dingen schrijven.
<papier wappert. Knippen>
Goed dat er wat zinnetjes tussen zitten. Fijn om mee te beginnen.
Zijn er ook kleurtjes?

S: Morgen pas, vandaag alleen zwart wit.

C: Ik zou er eigenlijk iets in willen zetten van garanties voor de fabrikant. Daar lees je veel over. Dat hij gegarandeerd piept als er iets aan de handig is. Als er iets mis gaat, en hij heeft niet gepiept. Das een goeie. Als hij niet piept zijn zij verantwoordelijk voor eventuele gevolgschade.
Cool. Das de voorkant.

S: Als je denkt dat je klaar te zijn, moet je het zeggen.

C: Misschien nog iets over uhh.. Mis ik nog iets?

S: Het is geen SO, het gaat om wat jij vindt.

C: Ik heb misschien nog wel iets.. iets van uhh. Iets van recenties van betrouwbare partijen. He.
Wat zijn betrouwbare partijen. TNO. Zoiets.
En misschien een financieringsplan.
<gelach>

start van de brochure. <gelach>. Aan jou de taak om jouw lievelingsbrochure te maken van de ZA. Zet erin wat jij belangrijk vindt. Of garanties die je wilt hebben. Hier staan dingen die je kan opplakken als je dat wilt. Je mag er ook bij tekenen.

S: Producenten?

C: Die willen meer verkopen. Misschien dat wij de generatie zijn die geen auto's kopen, maar misschien komt het wel weer terug door dit. Of benzinestations, die kunnen deals sluiten met navigatie diensten.

S: Okee, dat is het einde. [naam], dankjewel. Ik ga de flyer boven mijn bed hangen.

Uw persoonlijke eerste klas coupe.

S: Zit er nog een rangorde in wat je
      belangrijk vindt.

C: Ja, geen stress. Dan sneller, dan veiliger.

S: Hoe denk je dat andere partijen erover
      denken?

C: Dit is een heel individualistische flyer.
      Dat bedacht ik toen ik m maakte. Andere
      mensen denken meer na over,
      gezinsdingen. Mwah. Nee, valt wel mee.
      Misschien niet-consumenten: ik wou dat
      ik m ook had, of had ik maar genoeg
      geld.

S: En overheid?

C: Ja minder verkeersdoden, en filedruk. En
      ze moeten ook subsidie gaan verlenen.
      Das een soort afweging.

Interview non-consumer
C: Consumer
S: Steven Puylaert (interviewer)

15:45, 3th of July 2015

Before the record started the goal of the interview was explained and the role of the non-consumer
is explained.

Inleiding

S: Heb je een rijbewijs?

N: B rijbewijs, sinds 2009.

S: Verplaats je je veel met de auto of ook
andere vervoersmiddelen.

N: Met de auto of lopend tegenwoordig.
      Minder met de fiets. In Abu Dhabi altijd
      met de auto, vaker als bijrijder dan als
      zelfrijder. Misschien 50/50 ofzo. In Delft,
      of Nederland, af en toe op en neer naar
      Delft met de auto op en neer .

S: Wat vind jij de grootste problemen op
de weg?

N: Ik denk dat veel mensen dat zullen
zeggen, maar de weggebruiker.

S: Wat bedoel je daarmee?

N: De andere weggebruiker. Dat mensen
      niet altijd rijden zoals jij rijdt. Meer ook
      dat ik weer zit te denken hoe van mij

zouden kunnen rijden, en alle regels kunnen
volgen, en met andere auto's ook nog
wel, en obstakels en glazenwassers op
de weg. Maar zodra er geen 'regels' zijn,
zoals bij fietsers, die steken schuin de
weg over. Zelfde met voetgangers, maar
die zijn langzamer. Dat is nog heel erg
onvoorspelbaar. Daar zijn moeilijk
implementeerbare aspecten. Het mag
niet fout gaan. Je kan niet zomaar een
fietser doodrijden. Die doen met 25
km/u domme dingen, en dan heb een
enorme veiligheidsfactor nodig. Dat is
niet te doen in een drukke stad. Elke
keer trapt die auto weer keihard op de
weg, om te zorgen dat het veilig blijft.

S: En wanneer zie jij zelfrijdende auto's
voor je? Qua tijd?

N: Ik denk best wel snel kan komen. Maar

verwacht wordt.

S: Hoe bedoel je dat?

N: Dat, uhh, in de emiraten rijden ze heel anders dan hier. En in de Emiraten kun je dingen doen die hier als vrij associaal geacht wordt. Terwijl dat daar helemaal assicoiaal is, of niemand zich dat aantrekt. Hier zit ik op mijzelf te letten om niet associaal te zijn.

S: Stoor je je dan vooral aan andere?

N: In Abu Dhabi vooral aan andere weggebruikers, hier minder, veel minder. Hier doen mensen meer normaal op weg. Hier ben ik meer bezig ben of ik zelf wel normaal doe.

S: Heb je nog andere dingen die je als problemen ziet?

N: Ik houd niet zo van vrachtwagens, helemaal niet van inhalende vrachtwagens. En van flitspalen ook niet zo. Dat komt misschien omdat ik net een boete heb gekregen.

S: Wat is jouw beeld wat jij hebt bij zelfrijdende auto's?

N: Dat ze op in een lege stad helemaal perfect

N: Ik denk dat het heel goed zou kunnen werken. Helemaal als de auto's ook een beetje met elkaar communiceren. Dan denk ik dat je veel files kan oplossen. Dat het ook best een stuk veiliger kan worden. En dat vrachtwagens niet meer hoeven in te halen. Ik denk dat het daarin wel voordelen kan hebben. Wat ik zei met communiceren, dat moet erin, dat ze een file aan zien komen. Dan gaan ze een beetje langzamer rijden. Als de file dan weer net oplost, dat hij dan enigszins door kan rijden. Niet met z'n allen vol in de remmen gaan. Dat dat geleidelijke kan verlopen.

S: Ben je voor dingen bang?

N: Nou, zolang er een rem in zit, en een stuur. Nou, dat is niet waar. Dat zou ik zelf willen, maar niet voor andere willen.

alleen maar op bepaalde stukken. Dat er soms staat "zet hier je autopilot uit", op de snelweg moet dat prima lukken. Denk dat dat er wel redelijk snel van gaat komen. Binnen een paar jaar. Het is adaptive cruise control uitbreiden. Met bochten maken. Dan heb je in ieder geval een zelfrijdende auto, maar nog niet zelf-oplettende-auto.

Vragen

S: Leuk dat je al dat verschil noemt. Er zijn verschillende levels, level 0 is geen automatisering, level 5 is het eest vergaande, geen stuur in de auto. Mijn onderzoek gaat over level 3. Dat zit middenin. En dat is een auto die het grootste deel van de rit zelf kan, en ook zelf oplet. Maar op bepaalde stukken aangeeft 'ik kan het nu niet aan', je kan dus een krantje lezen bij wegwerkzaamheden dan begint hij te piepen. Je hebt dus nog steeds een rijbewijs nodig en kan niet dronken in de auto zitten. Begrijp jij dit?

N: Ja.

S: Waar wordt je enthousiast van, of laat ik als eerst zeggen, wat vind je hier van?

omvallende container mag je nog wel aanrijden, als de auto's achter je dan niet op je botsen. Als een kind en een omvallende container tegelijkertijd de weg op duiken, dat je dan de container aanrijdt, en niet tegen het kind.

S: Dus veiligheid.

N: Ja zeker. En ik denk ook dat het heel oncomfortabel rijden is.

Creatief

S: Okee. Het creatieve gedeelte. Autos hebben altijd een mooie brochure erbij. Jij hebt een beetje een rare brochure. Jij gaat hem namelijk niet zelf kopen. Toch wil ik vragen of jij een brochure wilt tekenen voor jouw ideale zelfrijdende auto, gekocht door anderen. Hier zijn

Dan gaan mensen toch ineens keihard remmen en alarmlichten aanzetten. Op zich niet echt. Ik denk dat zo uitvoerig getest kan worden. Ik denk dat het niet 1 auto op zich is. Als het echt per auto is, geen communicatie, daar zou ik wel bang voor zijn. Als alle auto's met elkaar communiceren. Ik weet niet wie matrixborden aanstuurt, maar als bijvoorbeeld Rijkswaterstaat op de A4, dat die zeggen dat je met alle wegwerkzaamheden zelf mogen rijden. Daar zetten we het uit. Je kan het alleen gebruiken als alle auto's om je heen dat ook kunnen. Dan zou ik niet zo bang zijn.

S:	Je hebt het nu vooral over snelwegen, als je nu naar andere type wegen kijkt?

N:	Niet zulke drukke wegen zou nog kunnen. Maar het centrum van een stad, of woonwijk, zou ik het niet doen. Zodra er drempels en stoplichten zijn, dan niet.

S:	Waarom dan niet?

N:	Omdat daar teveel chaos is. Om te regelen. Die chaos kan je niet regelen van bovenaf. De fietser en de bromfietser zijn niet bestuurd door Rijkswaterstaat.

S:	Waar ben je dan bang voor?

N:	Nou, ik ben bang voor dat een auto hoe te reageren als er een kind oversteekt. En geen afweging kan maken. Dat een auto niet het verschil ziet tussen een kind en een omvallende container. Tegen een functionaliteiten uit je normale auto.

S:	Zijn dit ook voordelen voor jou als niet-consument.

N:	Nou, niet echt. Maar het wordt ook voor mij veiliger, en zal ook efficiënter gaan op de weg.
Ik zou stemmen op de partij die een zelfrijdende auto regelt. Ook al rijdt ik er zelf niet in eentje.
Er hangt veel meer mee samen dan alleen comfort, als iedereen op elkaar let

wat hulpmiddelen erbij. Dit is hoe hij eruit moet komen te zien. Wat hulpmiddelen, je mag knippen, plakken, maar ook overschrijven, of erbij tekenen.

N:	Nu snap ik de pritstiften.

N:	Je hebt echt een goeie auto uitgezocht. Dit is echt mijn lievelings. Mazeratti.

N:	Wat ga je dan met deze brochure doen?

S:	Analyseren. Dat leg ik straks wel uit. Maar als je niet wilt zal ik hem niet aan het publiek ten toon stellen.

N:	Ok. Prima hoor.

N:	Mag ik ook mijn eigen infrastructuur erbij bedenken?

S:	Hoe bedoel je dat?

N:	Nou, ik wil een zelfrijdende autobaan erbij.

S:	Ok. Hoe zit dat dan?

N:	Dat zelfrijdende auto's op die baan moeten.

S:	Waarom wil je dat?

N:	Dat zal de innovatie stimuleren, dan gaat het sneller.

S:	Mogen ze dan ook nog op de andere stroken?

N:	Uhhm, ja dat mag ook nog. Ze mogen op beiden.

S:	Okee.

S:	Wat heb je nog meer opgeschreven?

N:	Super comfortabel op je werk, en 25% minder onderhoudskosten, doordat je minder accelereert en remt. En je heb alle

en communiceert wordt het veel efficiënter allemaal. Het is meer dan alleen zelf rijden.

S:	Maar bijvoorbeeld zoiets als een extra strook, dat kan juist voor meer file zorgen op jouw strook als zij erop mogen.

N:	Ja, maar het werkt net als de carpoolstrook, of taxi strook die ook voor elektrische auto's gebruikt mocht worden. Dan gaan mensen m eerder kopen.

S:	En zou je bijvoorbeeld een auto accepteren die voor meer veiligheid zorgt, maar slecht is voor de doorstroming? Dat hij bijvoorbeeld een volgafstand van 3 seconden heeft, of heel vaak remt, waardoor iedereen daarachter in de file staat.

N:	Nee, dat zou niet mogen. Het moet wel beter zijn dan de vorige versie. De rest moet er geen nadeel van ondervinden.

S:	En zou je het goed vinden als je door een dal van onveiligheid aankomt, om weer extra veiligheid te krijgen?

N:	Nee, je kan niet zomaar experimenteren. Het moet beter zijn dan de huidige auto. Op alle aspecten. Je kan niet zomaar ineens minder goed worden dan dat het nu is. Elke stap moet veiliger en beter zijn dan de vorige.

Interview government
P: policy advisor at Rijkswaterstaat
S: Steven Puylaert (interviewer)

Inleiding

S: Klopt het dat jij in zelfrijdende auto team de overheid zit?

T: Ja.

S: Hoe werkt dat team en wie zitten daar nog meer in?

T: Naar aanleiding van de ambitie van de minister is er een werkgroep in het werkgroep in het leven geholpen. Die wordt getrokken door Florien van der Windt, van DGB (Directoraat Generaal Bereikbaarheid). En daar zit de RDW en Rijkswaterstaat (RWS) bij. Omdat je de combinatie van voertuigen en weg nodig hebt. Andre van Lammeren zit in de stuurgroep. Loes Aarts en ikzelf zitten in de werkgroep. Wij doen namens RWS werk om de ambitie van de minister te verwezenlijken

S: Dus de brief die Schultz naar de kamer heeft gestuurd….

T: Ja, meer testen. De kern van de ambitie die zij heeft uitgesproken is dat zij testen op de openbare weg mogelijk wil maken, maar er spreekt veel meer uit. Kennis ontwikkeling, je hebt een doorkijk nodig naar de toekomst. Ik zit er vooral in voor de kennisontwikkeling. Het in kaart brengen welke kennis er is en ontbreekt.

S: Ja. En, wat zijn de belangrijkste taken voor het team in het geheel?

T: Er zijn een 4-tal taken te onderscheiden. De eerste is gericht op het mogelijk maken van testen op de openbare weg. Daar zijn twee zaken voor nodig: daar heb je voor nodig dat het juridische mogelijk wordt, een belangrijke juridische component in. Per 1 juli gaat de nieuwe algemene maatregel van algemeen bestuur in dat dit mogelijk is in Nederland. Daar is door het team hard een aantal stappen voor die doorlopen moeten worden voordat je op de openbare weg mag testen. Dan zijn er nog twee belangrijke onderdelen: enerzijds de kennisagenda, waar ik voor aan de lat sta. Dit is gericht op de korte termijn en de lange termijn. Nu is ad-hoc kennis nodig voor de aanvragen, te faciliteren. Op de langere termijn is er kennis op verschillende domeinen nodig om beleid te kunnen vormen. Om een beeld te kunnen schetsen hoe je hiermee verder wilt. En hierbij is de propositie van Nederland gekomen: Nederland als testland verkopen. Waarom zijn wij een geschikte locatie om te testen, en een van de ambities die de minister heeft uitgesproken is dat ze graag koploper wilt zijn. Hoort ook dat je daar reclame voor maakt, mensen uitnodigt om te komen. Want als we de procedures allemaal hebben, het land is geschikt, maar niemand wilt testen, dan houdt het op.

S: Wat is eigenlijk het beeld wat hoe je Nederland over 10 jaar zou zien?

T: Hoe ik?

S: Nou, Rijkswaterstaat of de werkgroep

T: Dat is wel lastig om een helder beeld bij te schetsen. Met name omdat in de discussie over de zelfrijdende auto er vaak over het eindbeeld wordt gesproken. Maar niet over het transitie pad daarnaar toe. We zitten nu volop in de transitie naar coöperatieve ITS, en we zien nadrukkelijk dat automatisch rijden en coöperatieve ITS met elkaar verbonden zijn en er een samenhang is en aanpakken. Zoals dat in goed Nederlands heet: het deployen van een coöperatieve tak, en het verder brengen van het kennis brengen omtrent automatisch rijden. En daar realistische scenario's en paden in te

aan gewerkt. Het tweede onderdeel daarvan is dat er een toelatingsprocedure ontwikkeld moet worden. En, uhhm, die is er nog niet. Maar samen met de relevante wegbeheerders en de RDW en het DGB wordt zo'n procedure ontwikkeld. Daar zijn

Wij zijn wel een belangrijke partij. Je hebt wegbeheerders wel nodig om het mogelijk te maken. En de vraag daarbij die wij ons op dit moment stellen is "wat moeten wij doen aan infrastructurele zijde om automatisch rijden mogelijk te maken". En dat speelt zich zeg maar af tussen enerzijds dat de opvatting dat het automatisch voertuig klaar moet zijn voor onze wegen, en we moeten de wegen klaar maken voor automatische voertuigen. Het is onduidelijk of daar aparte stroken voor aangelegd moet worden, of dat je communicatie een stap verder moet brengen. Dat is zeg maar te onzeker om te zeggen hoe het er over 10 jaar uit zou moeten zien. Ik verwacht wel dat er binnen nu en 10 jaar op een aantal locaties, op dedicated infrastructuur, hoge mate van automatisch rijden mogelijk is. Ik vind wel dat de stap van level 2 naar level 3 automatisering dermate fundamenteel is dat ik daar geen kratje bier op durf te zetten en daar een datum bij te zetten.

S: Meer duidelijkheid voor Rijkswaterstaat en grootschalig testen

T: Grootschalig testen en aan infrastructurele zijde alvast een voorschot nemen op het mogelijk maken van. En, dat zit wat ons betreft deels in het verder gaan in het door ontwikkelen van cooperative ITS, omdat we dat als een belangrijk onderdeel zien van automatisch rijden. De connectivity aan de infrastructuurkant, is zegmaar een belangrijke bijdrage van RWS. Daarnaast

kiezen. Wat voor RWS heel erg van belang is om de impact op de infrastructuur in beeld te brengen. Eeen… Bij.. Wij realisteren ons dat wij maar een partij in de hele keten zijn, wij kunnen niet als enige partij in Nederland automatisch rijden op de weg brengen.

ruimte. Het is heel erg lastig om, dat is denk ik een van de reden waarom automatisch rijden nog niet op de weg is. Die zwakste schakels in dat totaal, die bepaald natuurlijk de snelheid. Het is niet de snelheid van de ICT ontwikkeling. Het is de snelheid in voertuigen en in infrastructuur. Dat wordt door veel *believers* in voorspellingen, van over 5 of over 10 jaar is tie daar, vergeten.

S: Misschien is er 1 maar nog niet het gros van het wagenpark.

T: 1 moet er wel kunnen zijn over 10 jaar.

Vragen

S: Je had het al over niveau 1 2 en 3. Mijn onderzoek gaat over niveau 3. Jij weet volgens mij exact hoe het zit. Dus als hij gaat piepen moet je het stuur over nemen, maar anders kun je de krant lezen in de auto. Nog altijd wel een rijbewijs nodig.

T: Waar het lastige daarbij is, inderdaad, hoe dat precies wordt vormgegeven. En hoeveel tijd je in hoeveel tijd nodig hebt om te reageren.

S: Waar wordt RWS enthousiast van als je aan level 3 denkt?

T: Nou als we aan level 3 denken worden we niet noodzakelijkerwijs enthousiast. We worden enthousiaster van level 5. Met name omdat het veiligheidsaspect en human factors aspect van level 3 nog onbekend is, wat de impact ervan is. De vraag die wij ons daarbij stellen, als je het voorstelt dat level 5 het hoogst haalbare is in termen van veiligheid en

zullen we zorgen dat de procedures voor aanleggen van nieuwe wegen, dat het niet onmogelijk wordt gemaakt om. Niet alleen geld, maar ook fundamenteel ook in hoe je de weg aanlegt. Hoe je snel kunt inspringen op behoeftes.

We hebben met 3 grote tijdspaden te maken. Die verschillend lopen: het tijdspad van ICT, in termen van enkele jaren. Tijdspaden van voertuigen, ligt rond de 10 jaar. Hardware en software kan dan uit elkaar worden getrokken. Tijdspaden van infrastructuur die liggen tussen de 15 en 30 jaar. Ook daar kun je hardware en software uit elkaar trekken. Dat creëert nog wat

garanderen dat er een periode van grotere veiligheid komt. Er wordt wel eens een parallel getrokken met de introductie van de autogordel. Die leverde ook gevaarlijke situaties op, er zijn mensen verdronken die niet op tijd uit de auto kwamen. Je hebt slachtoffers, maar uiteindelijk hebben autogordels ons veel meer veiligheid getrokken. Hier zitten wel parallellen, maar ook fundamentele verschillen.

S: We hebben het vooral gehad over waar RWS bang voor is, maar waar wordt RWS enthousiast van?

T: Wij worden enthousiast van dat we uiteindelijk een positieve ontwikkeling heeft op de verkeerstroom: veiligheid en efficiency. Impact op het milieu. Mogelijk betekend het ook dat we, in het verlengde van dynamisch verkeersmanagement, dat we minder aan hoeven leggen. Minder hoeven bouwen. Dat je daarmee knelpunten kunt opvangen. De echte benefits zitten in niveau 4/5, waarbij je ook andere voordelen krijgt. Andere groepen worden mobiel. Dat mensen ook fundamenteel hun tijd anders kunnen besteden. Dat betekend ook dat de

efficiency en mooie maatschappelijke baten, zit er dan een dal in de weg daar heen en ga je dan stijgen. Dat is onduidelijk. En als dat via een dal is, is dat ook acceptabel. Accepteren wij als maatschappij dat wij dit voor het grotere doel doen. Of zeggen we nee, want daarmee verlaagt het niveau.

S: Zou RWS bereid zijn om door een dal te gaan?

T: Dat is echt een fundamentele vraag. ….

Ik denk het niet. Ik denk het niet. Niet zonder meer, omdat het heel moeilijk te verkopen is. Je accepteert dan een periode van onveiligheid zonder dat je echt kan

zijn ook voorbeelden die niet opgenomen kunnen worden.

In die zin is het lineair doortrekken van de brochures die er nu zijn. Veiliger, vlotter, maar je moet nog steeds blijven rijden. Dat is wel jammer. Daar is de afgelopen 100 jaar niets in veranderd. 100 jaar lang moet je je handen en voeten gebruiken om snelheid en richting te bepalen. En dat kan nu makkelijker. Dat is de belofte.

S: Zijn er garanties die van de fabrikant gegeven kunnen worden. Zodat de RDW ze zal goedkeuren, niet alleen voor testen, maar ook voor op de weg.

T: Ja, eigenlijk, daar zijn we nog niet uit. Ik denk dat we garanties van level 4 vragen, voor level 3. Die twee levels vloeien in elkaar over. Level 4 belooft dat het systeem niet meer aan kan, dat hij op een veilige manier tot stilstand komt. Desnoods een schietstoel. Je moet wel zorgen dat dat niet in een tunnel gebeurd. Je ziet dat ik niet zo creatief typ ben in deze zin. Ik verwacht ook geen mooie tekeningen. Het is het doortrekken van de beloftes die we nu hebben.

Wat wel een fundamenteel verschil is als je het linkt aan verkeersmanagement, is

noodzaak om files weg te nemen veel minder wordt.

Creatief

S: Zoals ik al zei zit er ook een creatief deel bij. Stel zelfrijdende auto's komen op de markt. Dan zit er waarschijnlijk een brochure bij, en mijn vraag is eigenlijk, hoe ziet de perfecte brochure van de perfecte zelfrijdende auto van Rijkswaterstaat van level 3 eruit. Om te helpen staan hier wat woorden en plaatjes op. Dan hoef je niet helemaal 'from scratch te beginnen'. Stiften, prit en schaar zijn hier, in de creatieve set.

T: Je verwacht dat ik hier nu even een brochure maak.

S: Hij hoeft niet fantastisch mooi te zijn.

T: De belofte is natuurlijk: veiliger en vlotter en comfortabeler. Geen reclame voor anders inrichten van de tijd die besteed wordt. Je moet nog steeds monitoren, dan zou je wel los kunnen gaan. Kamertjes op wielen, waarin va allerlei dingen mogelijk zijn. Dat voertuig het onmogelijk kunnen maken om te hard te rijden. Dat is wel een stap verder van informeren naar meer sturen.

S: Dat zit dan in de ideale auto?

T: Ja.

S: Stel de zelfrijdende auto heeft geen doostromingsvoordelen, misschien zelfs nadelen. Waar in de spits toch 1,5 gebruikelijk is, en dat hij ineens 2 sec afstand wilt houden.

T: Dat is maar de vraag of we dat veilig vinden.

S: Stel, het is veilig, maar de doorstroming gaat omlaag. Wordt die toegestaan?

T: Daar wordt onze minister minder enthousiast van. <lang denken> . Ik denk het niet, ik denk het niet. Alhoewel RWS wel een cultuur heeft waarin de veiligheid preferen boven de efficiency. Is het de vraag of een kleine

dat wij nu ons best doen om de bestuurder zo goed mogelijk te informeren, en die persoon moet daar zelf iets mee doen. En, de belofte van level 3 is dat een deel van die informatie gebruikt kan worden om delen van je rijtaak over te nemen.

S: Dus wil RWS sturen over het netwerk?

T: Uiteindelijk wel. Maar mind you, daar zit een verschuiving van dat we in de situatie dat er niet zo veel aan de hand is. Free flow. Zo veel mogelijk terugtrekken. Maar op moment dat zeg maar de maatschappelijke baten in het gedrag zijn. Maatschappelijke randvoorwaarden in het gedrang komen, netwerkoptimum of veiligheid dan willen we wel de mogelijkheid hebben om te kunnen grijpen.

S: Dwingend?

T: Ja. Dan is dus wel de belofte dat we dat deels geautomatiseerd kunnen doen. Dan zou je weer de oude discussies rondom ISA op kunnen rakelen. In principe zou een level 3. ieder geval jammer.

S: Spanning dus.

T: Ja.

S: Wat vindt je van het rapport 'Tem de robotauto' van het Rathenau?

T: Ze maken een valide punt, over wat ik hiervoor zei. Het inboeken van de maatschappelijk baten kan alleen met connectivity. Dat onderschrijf ik wel. Misschien is de titel wel provocerend bedoeld, zo komt hij over op andere. Richting google moeten we zeker wat meer moeite doen om ze hier te laten testen. Zij vatten het op als een waarschuwing.

S: Hebben ze dat gelezen.

T: Dat hebben ze gewoon gegoogled. < gelach> Dat zagen ze als een aanval. Temmen is toch dat andere zich met jou gaan bemoeien. Dit is trouwens wel een mening die meer partijen delen. Ook

veiligheidswinst een groot capaciteitsverslies rechtvaardigt. Afhankelijk van wie er dan aan het roer staat <gelach>., maar dat is de reden dat wij propageren dat de combinatie van automatisch rijden en coöperatief rijden samen gezien moet worden. Wij geloven dat de toevoegen van communicatie het veiligheidsaspect kan vergoten zonder dat het leidt tot capaciteitsverlies. Alleen de eigen sensoriek is per definitie, zwakker dan dat je met communicatie kan creëren. Dat is dus reactief of proactief zijn. Je zet het menselijk reactievermogen buiten spel. Van één seconde kun je naar fracties van miliseconden gaan, maar het is nog steeds reageren op je voorganger. Je anticipeert dus niet op 2, 3 voertuigen vooruit. Communicatie kan dat wel. Wij proberen het pad te vinden dat zowel veiligheid als efficiency vergroot. Omdat wij niet de beperking willen hebben van de keuze, of het een, of de ander. Dat hoeft niet.

Die keuze komt wel naar voren, als je, zoals de meeste OEM's wel doen, zeg maar, vanuit je eigen autonomie benaderd. Automobiel fabrikanten willen vaak niet afhankelijk zijn van andere partijen. Ondanks dat toevoegen van communicatie grote voordelen kan bieden, willen ze om andere redenen graag onafhankelijk zijn. Nouja, dat vinden wij in

bijvoorbeeld de Amerikaanse overheid gelooft ook in de combinatie van connected en autonomous, en dat dat maatschappelijke baten gaat geven. Alleen de OEMs facaliteren leidt tot maatschappelijke kosten.

B: Designer drive dynamics
A: Designer level 3 automation
S: Steven Puylaert (interviewer)

10:15, 19 June 2015

(off-tape: Steven has introduced his research and the interview set-up. B explained he works on current automation systems.)

Introduction

A: Let me introduce myself as well. I am ….
        …, I am now working for [name

Do you mainly see this as a technology push, that we can do this with technology, or a market pull, that the

manufacturer] since 1 year (also did 2 internships at [name manufacturer], author) and since then I worked mainly on [name project] project and in advanced travel systems or self-driving cars. Mainly in the near future. I am software engineer from origin.

S: Ok. I might explain a little about the interviews. Most where face-to-face, there was a creative part in it, but I think I will do it slightly different, since we're doing a telco. The interview mainly consists of questions, halfway the creative part starts, but I changed that set-up. Some took 15 minutes, others 40.

A: Ok.

S: During the whole interview I ask questions about not what you think but about what [name manufacturer] thinks.

A: So I really [name manufacturer]. Ok, that's very important, so I not any car manufacturer, but I am just here for [name manufacturer]

S: In my transcript I won't state that you are from [name manufacturer], just you are a car manufacturer. I anonymize that all.

Questions

Ok. What was the reason for [name manufacturer] to start developing automated vehicles

A: So for me, that was a process. We are working on driver assistance systems since 20 years. We started with [name project], [name project], CC, ACC, from there it was a small step, or the normal cause of things to advance assistance systems, Like lane changing assist. Next step is self-driving cars, level 3. The reason is a cause of development.

S: Yes. Yes. Nice vision. And these level 3 cars, you explained. Where do you get excited from if you look at level 3?

customer wants it?

A: That's the development, the technology thing. Marketing will come, because we are now at the time we can do this.

S: Yeah, and you are researching 'hochautonomisch fahren' or level 3?

A: That's the same thing I guess. Level 3 is highly automated driving.

B: That's the terminology that we use here. If there is still a driver involved it's 'hochautonomisch', but if the situations is so that the driver needs to take over he should do.

A: Ok, the same thing. The system can take over all the driving tasks. The driver is out of the loop, but sometimes needs to take over.

S: Yes, than we have the same definitions. If the car gives a signal, than the driver needs to take over.

A: Yes. Ok.

S: How do you see driving in 10 years from now?

A: Ten years, let's see, that's 2025. In city there will be autonomous vehicles, like the google cars. Really slow autonomous vehicles. May not be allowed to drive on every road. Only in downtown, or pedestrian areas. They will be there for elderly or disabled people. Like car sharing, you can rent them.

S: More public transport?

A: Yes. Not for goods, but for people. Outside the city there are normal cars. And on highways I see highly automated cars. So level 3 cars. Where you can manually drive and in the car and on highways the car drives you to the next big city, where you take over. That's my vision of 2025. So two kind of cars. One is the level 3 cars, and really autonomous in cities in pedestrian area's

more communication between the car and the driver, and not between the cars.

A: I get excited from the imagination that you are allowed to do something else while driving. The car is driving you, and even when something happens, that you are not responsible.

S: So in level 3 you see [name manufacturer] as responsible

A: Yes, as long as the car has taken over. Is out of the loop. And they have nothing,… so the system makes a failure. When it comes to an accident, so the driver does not make a mistake. At least that the driver is not responsible. The car manufacturer or some insurer. That's as driver the most interesting thing. But this was as [name manufacturer] right? I was now answering as a customer.

S: I am interested in both, so that's no problem, but as a car manufacturer?

A: As a car manufacturer I would say, the most excited thing, is…. Mmm. The cooperative driving, the shared control, at some point the functions, the car is driving, is responsible and at some point it has to take over. In this cooperative control is where I get most excited from as a car maker.
Think of the google car. They have no steering wheel or pedals. There is no cooperative driving. Think of a [name manufacturer] you can buy now. There are assistance systems with a cooperative part, but there is still no level 3 self-driving car. The thing where I get most excided we have level 3, driver assistance, and what do we do with the driver, and the cooperative.

S: Ok. This is where you get excited from, are you also afraid of some aspects of level3?

A: For car manufactures that's the same thing as I am excited about. I look forward for the solution for this. And it is the same thing as I am afraid of.

S: How car manufacturers work together?

S: So the human factors.
Are you also interested in the capacity on the road

A: Yes of course. More the marketing thing is that the self-driving car can reduce accidents, and the number of people who are dying reduces. We want to reduce the change on highways. So increase the capacity on the road. That's what were interested in. That's especially a marketing thing.
But capacity won't be the first reason to buy a self-driving vehicle for a customer.

S: You probably heard of the two scenarios: a cooperative car, or an autonomous car. Which one of the two is more favourable?

A: A combination of course. But for self-driving cars it would be great that the car is intelligent, but also can communicate with other cars and road infrastructure. But for a first step it's not necessary. It's more realistic that first autonomous would be developed. It would be best to have both, but this is more likely.

S: So you see the connected scenario more for level 4 and 5?

A: Yes, first automation than connected cars.

S: First an autonomous vehicle, than a connected.

A: That is what I would say is the realistic scenario. Maybe not the best.

B: There are also other factors.

S: And the best?

A: Every car can communicate in unified cars.

S: Image you have built a car, its safe and comfortable. But it's not good for traffic flow. Would you bring that to the market?

A: I don't think that's realistic

S: But. If the headway is standardised at 2,5 seconds to be safe?

B: You mean how car to car communication to car communication as well?

A: No I don't think that's a big problem. I don't think if we really need this for level 3 cars. The connection is not the main problem. Its

market if it's worse for the capacity.

S: Ok. Fine. Imagine the self-driving car is available in stores. With the car a sort of flyer comes there. The flyer states what the car can do, and is capable of. What stands in your favourite flyer?

A: Did you hear of Volvo that they have the aim that nobody is dying in a Volvo? That would be my first argument. On the first page.

S: What would be on the second page?

A: I won't go to capacity, but to really spend your time different. Reading emails, or working. That will be my second arguments

S: And page 3 or 4?

A: Page 3 would be also disabled or very old persons can be mobile by having a self-driving car.

S: The higher comfort is on page two right?

A: Comfort in this term that he can use the time to work, not that its more comfortable to work

S: On the first page you state that no one in a Volvo, or let's say a [name manufacturer], may die. But on which page are accidents with other road users?

A: Of course you can't promise that there are no accidents on the roads, as long as there are no other cars on the road, only self-driving, than you can guarantee that no one is dying in the car. But if someone else is colliding with you. We have avoidance, reducing the fatalities in the car.

S: I might buy one.

A: 150.000 bucks

S: That's the price of a level 3 car?

A: I would bring it to the market if it has less accidents. Than it may reduce the traffic flow, if it has a headway time which is larger than a normal car. I would still bring that to the market. For customers capacity is not the first argument. That is that you can do something else. I would bring it to the

A: For a I3, for a 7 series you have to pay
      more.
S: Than I'll go for the advanced version.
(conversation continues about the research
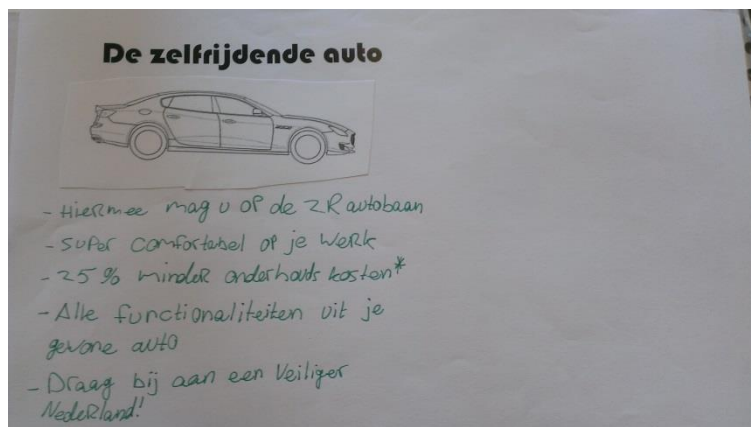   itself.)

Appendix J: scans creative elements interviews
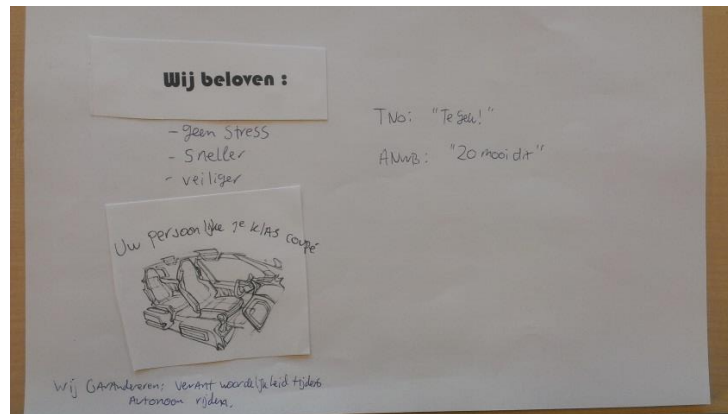
Flyer consumer
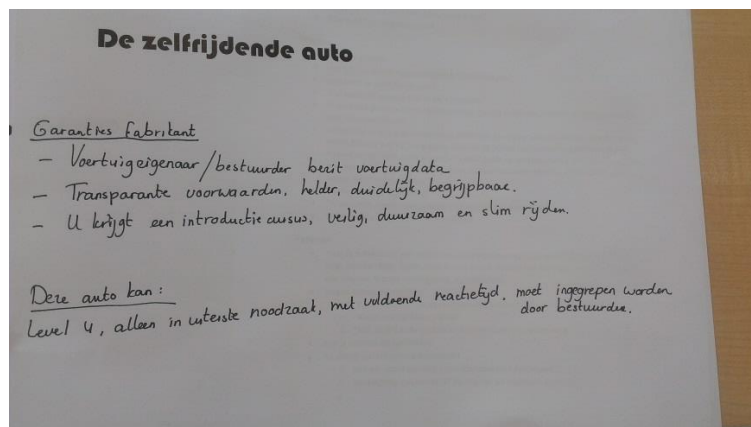
Flyer ANWB

Flyer non-consumer

Flyer Government

Appendix K: Statements from interviews and the clusters they are part of

Spending time differently

Anders je tijd besteden is belangrijk
Comfortabel aankomen is belangrijk
Comfortabeler is belangrijk
Geen stress is belangrijk
Iets anders doen tijdens het rijden is belangrijk
Niet op hoeven letten is fijn
Ontspanning is belangrijk
Super comfortabel op je werk komen is belangrijk

Safety

Bijdrage aan een veiliger Nederland
De bestuurder mag geen proefkonijn zijn
Garanties van level 4 voor level 3 zijn belangrijk
Geen bestuurder komt om het leven
Gegarandeerd piepen bij gevaar is een noodzaak
Het is belangrijk dat alleen in uiterste noodzaak de auto overgenomen moet worden
het is belangrijk dat bedacht wordt hoe de mens computer interactie is
Het is belangrijk dat level 3 in de ontwikkeling wordt overgeslagen
Human factors meenemen is belangrijk
Ik ben bang voor auto's die niet communiceren
Ik ben bang voor de veiligheid in steden
Ik denk dat het veiliger kan worden
Minder sterfgevallen in het verkeer is belangrijk
Minder verkeersdoden vindt de overheid belangrijk
ook best een stuk veiliger kan worden
Veiliger is van belang
Veiligheid is belangrijk
Veiligheid is belangrijker dan efficiency
Voldoende reactietijd is belangrijk
Een introductiecursus krijgen is belangrijk
Een introductiecursus geven aan elke bestuurder is belangrijk

Accessible for everyone

Alle groepen mensen moeten er mee kunnen werken
De uitleg van een ZA op 1 A4tje is fantastisch
Een introductiecursus krijgen is belangrijk
Een introductiecursus geven aan elke bestuurder is belangrijk

Liability

Aansprakelijkheid duidelijk regelen is belangrijk
Het is belangrijk dat autofabrikanten verantwoordelijk zijn
Transparante voorwaarden zijn belangrijk
Verantwoordelijkheid bij ontwikkelaar als hij niet aangeeft om over te nemen is belangrijk

Self-determination

Als maatschappelijke baten in het gedrang zijn kunnen sturen is belangrijk
Data blijft van de voertuigeigenaar
Data-eigendom bij de bestuurder is belangrijk
De overheid moet kunnen beslissen waar de automatische stand uit moet
Het is belangrijk dat auto's van bovenaf niet alleen geïnformeerd kunnen worden maar ook geleidt of gestuurd kunnen worden

Equality

Alle weggebruikers moeten voordelen hebben
Er mogen geen voertuigen voorgetrokken worden
Het is belangrijk dat de rest van de weggebruikers geen nadelen ondervinden
Het is belangrijk dat het voor alle gebruikers van de weg beter wordt

Traffic flow

Auto's moeten communiceren om schokgoven te voorkomen
Capaciteit is belangrijk
Dan denk ik dat je veel files kan oplossen.
De files moeten weg
De gebruiker sturen over het netwerk is belangrijk
Efficiency is belangrijk
Efficiëntie op de weg is belangrijk
Ik denk dat er je veel files kan voorkomen
Minder filedruk vindt de overheid belangrijk
Minder wegen aan hoeven leggen is belangrijk
Sneller op locatie aankomen is belangrijk
Vlotter is belangrijk
Vrachtwagens hoeven niet meer in te halen
Het is belangrijk dat auto's van bovenaf niet alleen geïnformeerd kunnen worden maar ook geleidt of gestuurd kunnen worden

A few statements where not categorized in one of the value clusters.

Statement	Why not taken into account
Alle auto's moeten met elkaar kunnen communiceren	Has no normative statement only a requirement
Alle functionaliteiten uit je gewone auto moeten erin zitten	Not specific enough
Alle voordelen van huidige auto blijven behouden	Not specific enough
Andere groepen worden mobiel is van belang	Is per definition not true when level 3 is taken into account
De gebruiker moet meegenomen worden in ontwikkeling	Is about the innovation, not about the product
Gedeeld de auto sturen is belangrijk	Unclear what is meant
Het is belangrijk dat de innovatie gestimuleerd wordt door de overheid	Is about the innovation, not about the product
Het is belangrijk dat elke nieuwe auto beter is dan de vorige	Not specific enough
Het is niet erg als mensen anders gaan betalen voor mobiliteit	No effect of automated vehicles, but of policy

Appendix L: Example of the questionnaire

Online

Page 1: introduction

Page 2: introduction into automated vehicles (by movie or text)

Pop-up: role is extra explained

Page 3: Scoring of the points

Page 4: explaining why the respondent chose the top 2 and bottom 2

Bottomside of page 4

Page 5: any other remarks?

Questionnaire manufacturers (English)
http://rricollective.nl/autonomous-cars/

Page 1
The purpose of this graduate research project is to find out what your company finds important in the development of self-driving vehicles.

The questionnaire will take about 5 minutes.

Next.

Page 2
Explanation questionnaire

> This study attempts to find out what your company sees as the ideal self-driving vehicle. In literature and interviews, many aspects are mentioned about what is important about self-driving vehicles, but which ones is more important than the others? This survey only has only one central assignment: distribute 80 points over the 8 aspects. The more important you find an aspect, the more points you should award.

> All questions are about conditionally automated vehicles (level 3 of SAE). This means that the car drives by itself, but not under all circumstances. The driver can read a paper or do some work, but when the car beeps, the driver needs to take over the wheel within a few seconds.

> If you have questions, you can email to steven.puylaert@tno.nl

> <no pop-up>

Page 3
Question
Please distribute 80 points over the 8 different aspects. : the more important you find a certain aspect, the more points you should award. If you press *info* you get extra information about what happens when you give an aspect many of few points.
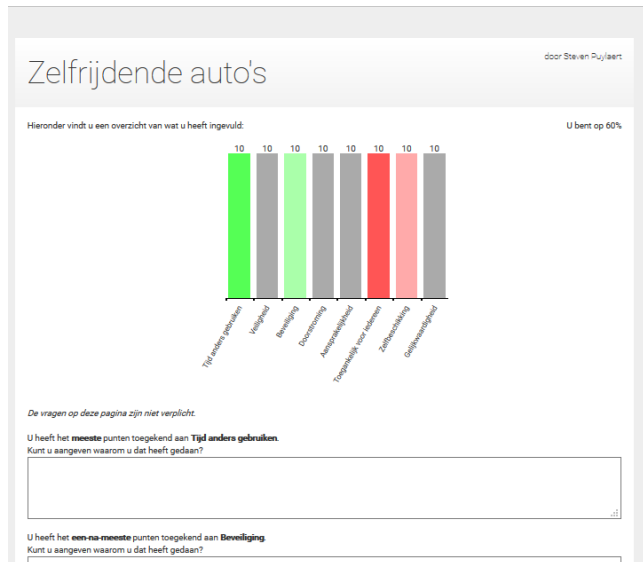
The ideal self-driving car is a car where

The driver can spend his/her time on something else than driving
To work, to check e-mails or read something while driving.

If you give many points, you state that
> Reading the paper, sending e-mails or watching movies should be almost always possible. Sleeping or drunken driving stays impossible as the driver needs to be able to take over the wheel within a few seconds.

> *If you give few points, you state that*

The computer drives, but the driver should constantly monitor the system. The automated function shuts down if you don't watch the road. Doing something else while driving is barely impossible.

Self-driving vehicles are safe
There are less, and less severe accidents.

If you give many points, you state that
New car models which enter the market should immediately be safer than earlier versions

If you give few points, you state that
Self-driving vehicles don't have to be safer than normal vehicles. Some are more unsafe, or more unsafe in an earlier stages and only safe after a few years.

Self-driving vehicles are secure
They should be hard to hack, to steal or to misuse.

If you give many points, you state that
Hacking, stealing, misusing or taking over the self-driving vehicle by malicious users should be impossible due to the adequate security.

If you give few points, you state that
The security of cars is given low priority. This makes stealing, hacking or even taking over vehicles something that can more easily happen.

The traffic flow is optimised
Faster from A to B, with less congestion and less emissions.

If you give many points, you state that
Self-driving vehicles should prevent congestion, shockwaves and jammed cities. They do this by keeping a short distance to each other, by sharing information or by cleverly making use of the road network.

If you give few points, you state that
Self-driving vehicles should hold larger distances to each other than normal vehicles, and therefore cause more congestion than in the current situation. Fuel consumption and emissions rise due to the congestions.

Drivers are not liable if there are accidents
Liability is arranged clearly and does not rest with the driver when the system is on.

If you give many points, you state that
Developers, producers or importers are liable for damage if the system is turned on. This damage should be handled without a lengthy legal process.

It is unclear who is liable. Through complicated juridical processes the damage can be reclaimed.

Self-driving vehicles are user friendly for everyone
All groups in society can work with all types of self-driving cars

If you give many points, you state that
Everyone, so also elderly or novice drivers, quickly understand how the car works. How the car works is equal for different types and models.

If you give few points, you state that
The working of different types and models differs and is hard to understand for not experienced drivers.

Drivers have a high degree of self-determination
The driver is in charge about the itinerary and speed, and is the owner of data generated by the vehicle.

If you give many points, you state that
The driver may decide what happens with the data the car generates. Besides that, the driver is in charge of the speed, the route and the place on the road.

If you give few points, you state that
A steering party (government, producer, other party) determines the speed, route and owns the data generated by the vehicle.

Self-driving vehicles and other cars are equal
None of the two groups will be favoured in the investments of the government

If you give many points, you state that
The government invests in measures which are beneficial for both the self-driving vehicles and the other vehicles. Both have an equal benefit from the investments.

If you give few points, you state that
Investments or subsidies only have advantages for self-driving vehicles. Examples include investments aimed at dedicated lanes or purchase subsidies.

Page 4
You can see here what you have filled in:

The questions on this page are not mandatory

You have given the most points to:
- Spending time differently

- Safety
- Security
- Traffic flow
- Liability
- User friendly
- Self-determination
- Equality

You gave second most points to …
You gave the least points to …
You gave the second less points to ….

Page 5
If you would like to have the results of this research, or participate in future research you can leave your email address here.

The questions on this page are not mandatory

Email address

Do you have any comments?
You can leave your comments or questions here.

Offline

Picture of the set-up at the *Back to the future* festival of Connekt

The background. Printed on A2

Appendix M: Script movie

Hallo, en welkom bij de enquête voor mijn afstuderen. Alvast bedankt voor het kijken van dit filmpje en het maken van de vragenlijst straks. Dit filmpje duurt 2 minuten, de vragenlijst waarschijnlijk nog eens 2.

Mijn onderzoek gaat over zelfrijdende auto's op de openbare weg. Dit zijn auto's waarbij de besturing deels of in zijn geheel is overgenomen door computers. Voorbeelden daarvan zijn de Google Car of de testen van DAVI die u hier ziet.

'Dé zelfrijdende auto' bestaat niet. Er zijn tal van verschillen. Simpel gezegd ontwikkelt de auto zich van een auto zonder automatisering, geleidelijk naar een auto met volledige automatisering. Geen automatisering is een simpele auto die u nu op de weg ziet. Volledige automatisering is een auto waarin geen stuur meer nodig is, en die alles zelf kan. Er is dan geen bestuurder meer en alleen maar passagiers.
Tussen deze twee extremen zit het niveau waarin de auto veel zelf kan, maar onder bepaalde omstandigheden de bestuurder zelf moet rijden. Over deze tussenvorm gaat mijn onderzoek en deze vragenlijst.

Bij dit niveau van automatisering kan de auto zelf rijden, zoals te zien is in dit filmpje. In deze tijd kan de bestuurder dus andere dingen doen. Bijvoorbeeld een krantje lezen of email beantwoorden. Als de bestuurder het wilt, kan hij of zij de besturing weer overnemen.

In sommige lastige situaties, bijvoorbeeld bij heftige regen of wegwerkzaamheden, piept de auto, en wordt gevraagd of de bestuurder de besturing weer wilt overnemen. De bestuurder moet dus nog steeds een rijbewijs hebben. Slapen of dronken in de auto zitten is ook nog steeds onmogelijk, aangezien u altijd binnen een paar seconden moet kunnen overnemen. Voor de mensen die bekend zijn met zelfrijdende auto's, het gaat dus om level 3.

Mijn onderzoek gaat erom wat u belangrijk vindt bij toekomstige zelfrijdende auto's. Uit interviews zijn 8 aspecten gekomen. Hoe belangrijk deze aspecten zijn, mag u nu bepalen. Deze enquête bestaat eigenlijk uit 1 vraag: verdeel 80 punten over de volgende 8 aspecten.

Uiteindelijk kunnen ontwerpers of beleidsmakers zien wat elke doelgroep van belang vindt, en dit als uitgangspunt nemen voor hun ontwerp of beleid.

Deze 8 aspecten zijn:
• Tijd anders gebruiken. Dit betekend dat je iets anders kunnen doen tijdens het rijden.
• Veiligheid. Minder en minder ernstige ongevallen.
• Beveiliging. Het onmogelijk maken van hacken of data misbruik
• Doorstroming. Het voorkomen van files op de snelweg en in steden.

- Simpel voor iedereen. Elke doelgroep er mee moet kunnen omgaan.
- Zelfbeschikking van de bestuurder. De gene die rijdt is de baas over het gedrag van de auto en de gegenereerde data.
- Gelijkwaardigheid zelfrijdende auto en andere auto's. Andere weggebruikers mogen geen nadeel ondervinden aan zelfrijdende voertuigen
- En als laatste: aansprakelijkheid. De aansprakelijkheid is duidelijk geregeld en ligt niet bij de bestuurder als het systeem aan staat.

Als u straks op volgende klikt ziet u dit scherm. Hier kunt u 80 punten verdelen over de waarden.

Als u op meer drukt komt is er extra informatie te zien, en staat er wat er gebeurd als u veel of weinig punten invult.

<ROL>

De hele uitleg is zo nog terug te lezen. Snapt u iets niet, of wilt u meer weten, mijn contactgegevens staan hieronder.

Dank voor de hulp!

ROL:

Rol consument

Bij het invullen van de vragenlijst mag er vanuit te gaan dat u een consument bent, u wilt dus een auto kopen. Verdeel de punten zo dat er voor u dé ideale auto van level 3 uit komt.

Rol niet-consument

Bij het invullen van de vragenlijst mag u er vanuit gaan dat u een andere weggebruiker bent. U rijdt, fietst of loopt in het verkeer, waar ook zelfrijdende auto's zijn. Verdeel de punten zo dat er voor u dé ideale auto van level 3 uit komt.

Rol overheid

Bij het invullen van de vragenlijst wil ik u vragen om namens uw overheidsinstantie de vraag te beantwoorden. Verdeel de punten zo dat er voor u dé ideale auto van level 3 uit komt.

Rol producent

Bij het invullen van de vragenlijst wil ik u vragen om namens uw autofabrikant de vragenlijst in te vullen. Verdeel de punten zo dat er voor u dé ideale auto van level 3 uit komt.

Appendix N: Value profiles before the workshop compared to the common value profiles

The common value profile compared to the value profiles before the test workshop

figure 4:

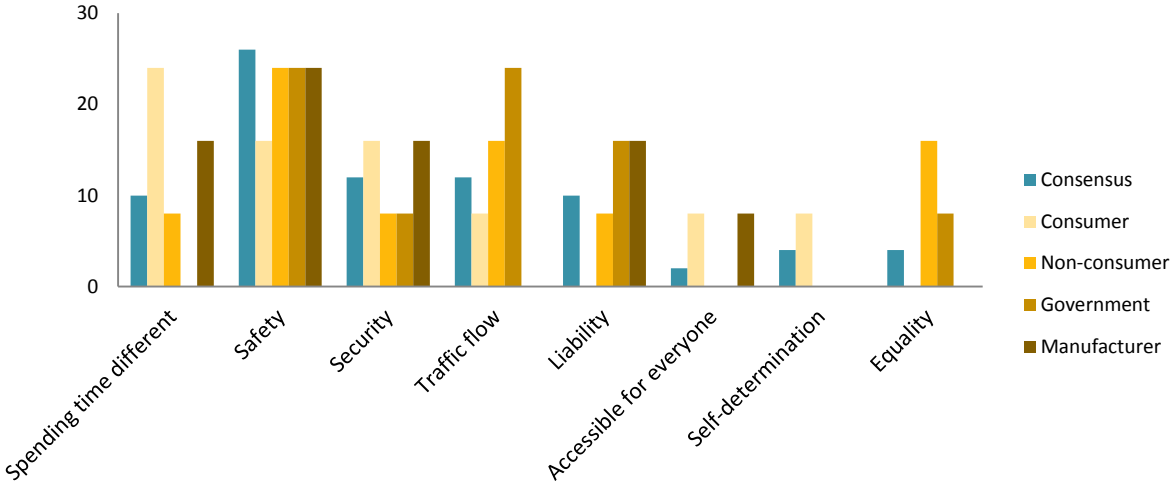- Most of the time around the average, but somewhat more extreme. So safety is found important, and it gets higher than the average (and even higher than all). The last three values all score less than the average.
- No real losers or winners.

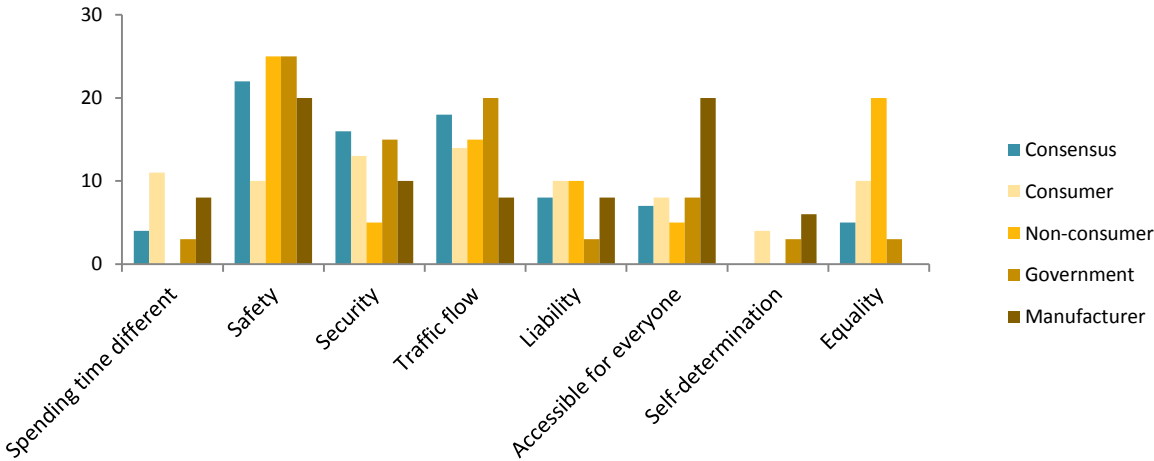*The common value profile compared to the value profiles before the first workshop*

figure 5:

- Most of around the average, somewhat more extreme
- No real losers or winners

Appendix O: Transcripts of the workshops

15.3. Transscript workshop 1

S = Steven	Facilitator / researcher
OV = Overheid	Government, student TU Delft
NC = Niet consument	Non-consumer, graduate TU Delft
C = Consument	Consumer, student TU Delft
AF = Auto fabrikant	Car manufacturer, graduate TU Delft

Introduction

S: Tof dat jullie mee willen helpen, jullie zijn hier om een proef te doen, het is dus geen creatieve sessie of iets dergelijks, maar een test. Jullie hebben allemaal een rol gekregen. Ik heb ze hier nog uitgeprint. We doen zo een voorstelrondje. Als je vragen hebt over je rol stel je zo even.

Het doel van vandaag is. Jullie hebben ook mijn enquête ingevuld volgens mij, toch? Ik heb eerst mensen geïnterviewd en daarna een enquête uitgestuurd. Uit die interviews kwamen 8 aspecten. Je mocht punten verdelen over deze 8 aspecten. Ik heb de enquête naar 4 partijen gestuurd: de overheid, autofabrikanten, mensen waar ik tegen zei dat ze zelf een ZRA hebben en andere weggebruikers.

AF: Ja.

S: Jullie zijn zelf een van deze actoren. Uit de enquête bleek dat mensen zelf een beeld kunnen maken, maar wat gebeurd er als je dit mensen vraagt samen te doen.

NC: eigenlijk een soort van stakeholder.

S: Ja, om dichter bij elkaar te komen. Stap 1 is het samen maken van deze enquête. Stap 2 is het concreter maken van deze 8 aspecten. Het eerste deel duurt best kort, het 2e deel wat langer. Ik zal dan wel uitleg geven.

(iedereen stelt zich voor. Eerst andere weg gebruiker, dan de consument, dan de autofabrikant, dan de overheid. Ze stellen zich voor en noemen uit zichzelf ook al wat ze belangrijk vinden. Iedereen zegt positief te zijn, maar wel onder zijn/haar voorwaarden)

S: (uitleg over welk type zelfrijdende auto het gaat.)

Deviding points solo

S: Iedereen krijgt 10 fiches. Zet ze in zoals jij dat wilt doen.

C: Dus vanuit je rol.

S: Ja, NC mag beginnen. Maar ik zal eerst het hele vlak met jullie doornemen (alle waarden worden uitgelegd door de sessieleider. Alle 8 de punten worden voorgelezen met kleine achtergrond. Ook bij wat er gebeurd als er veel of weinig punten worden gegeven. Zelfde uitleg als bij de enquête.)

NC: Ok. Meteen alles? Sowieso doorstroming is belangrijk. Ik wil snel naar mijn werk. Dat helpt mij ook als ik de auto niet heb. Maar, verkeersveiligheid is nog belangrijker. Ik heb er twijfels bij, het is een soort black box. Gelijkwaardigheid vindt ik ook belangrijk. Ik wil wel zorgen dat er nog steeds evenveel wordt geïnvesteerd in mensen die geen ZRA hebben. Op het moment dat ik er een zou kopen, dan tijd anders gebruiken, de beveiliging en aansprakelijkheid. Die krijgen er 1, dat vind ik iets minder van belang. Dat vind ik interessant aan de ontwikkeling, maar pas nadat alle andere dingen gecoverd zijn.

C: Tijd anders gebruiken vind ik het belangrijkst. Mail checken op de heenweg. Doorstroming vind ik daarna fijn, ben ik sneller op mijn werk. Ik zie het niet zoveel verbeteren. Verkeersveiligheid is wel

belangrijk, ik wil niet dat er een systeemfout is waardoor ik in de vangrail ligt. Ook beveiliging is belangrijk, dat hebben huidige auto's ook. Zelfbeschikking ook. Ik wil niet dat iedereen kan weten dat ik naar de wallen geweest ben. Ik heb liever niet dat die auto dat allemaal uitzendt. Nog wat naar tijd anders gebruiken, en gebruiksvriendelijk

AF: Eens zien. Veiligheid voorop, en de beveiliging moet goed zitten. Aansprakelijkheid moet goed zitten. Ik wil niet teveel in de problemen zitten. Eventueel subsidie,..

S: Meer subsidie is dus niet inzitten op gelijkwaardigheid, gelijkwaardig is iedereen evenveel geld.

AF: Oh, meer ongelijkwaardigheid wil ik dus. Ok. Dan nog gebruiksvriendelijkheid.

OV: Ik merk dat er voor de overheid een heleboel belangrijk zijn. Veiligheid, en doorstroming. Ook met de CO2 die minder wordt. Gelijkwaardigheid moet ook wel een tikje van belang zijn. Aansprakelijkheid ook. Misschien wel 2 fiches. Het levert ook veel gedoe op als er veel rechtszaken zijn. 1 ook voor beveiliging, lijkt mij onwijs onhandig als je criminaliteit in de hand speelt. Veiligheid en doorstroming te geven.

S: Nu krijgen jullie nog 40 extra punten die jullie samen mogen geven.

NC: oh, okee. Kut. Ja. Hoe gaan wij dat doen?

AF: Haha, ja

NC: Ok, veiligheid vinden we allemaal belangrijk volgens mij. Jij was die zwarte toch?

Step 1: dividing points together

(S deelt extra fishes uit zodat men kan zien wie welke kleur ook al weer was. Wat tumult omdat men elkaars punten toe probeert te spelen)

AF: We kunnen natuurlijk iedereen een 10 van de 40 geven, maar dat zou raar zijn aangezien zonder fabrikanten er geen ZRA komen.

OV: Gelach. Nee zonder de overheid komt er niks. Regelgeving ah, jammer.

NC: Laten we eerst zoeken naar common ground. Eerst wat aansterken. En misschien zijn er ook nog punten die we samen wel belangrijk vinden, maar waar niemand nu punten aan heeft gegeven. Het lijkt mij al dat verkeersveiligheid. Daar liggen van ons allemaal fiches, en vanuit ons allemaal bijna ook de meeste. Behalve de overheid. Nee, oh, toch niet, ook.

C: Ja prima.

AF: Waarom heb jij niks op gebruiksvriendelijkheid NC?

NC: Ik heb ze nog niet. Dus mij maakt het niet zoveel uit

OV: Waarom heb jij niks op doorstroming AF?

AF: Ja, heb ik niet zoveel aan.

S: Jullie hebben nog 10 minuten vanaf hier. Dat moet wel genoeg zijn.

OV: We hebben 2 insteken, of aansterken van wat we hebben of onderbelichte thema's bekijken zoals NC zei. Waarvan we toch achteraf denken wat we toch belangrijk vinden.

NC: Misschien hebben we inderdaad gebruiksvriendelijkheid onderschat. Al hebben we veiligheid gewoon erg veel gegeven.

AF: Dan doen we veiligheid er 12 bij, want er liggen er al ongeveer 12.

NC: Dus zelfde sterkte erbij. (Fiches worden verdeeld, verschillende mensen verdelen wat).

OV: Ja, maar zo doen we niet samen, nu doen we nog alleen.

C: Nou voor veiligheid vind ik dit prima, maar andere punten vind ik niet belangrijk.

NC: Ja, voor beveiliging geldt dat ook, daar hebben we allemaal fiches opgelegd.

C: Ik vind die tijd belangrijk. NC: Ik ook wel, maar wel minder dan jij.

OV: ik vind dat niet belangrijk. AF: Hoe zo niet? Efficiëntere mensen is toch meer economische groei?

NC: wat is het nadeel? OV: Het is niet onbelangrijk, het is meer dat ik andere punten belangrijker

vindt. Ik vind het een mooi neveneffect. AF: Al kan tijd anders gebruiken wel een driver zijn van meer.

C: Ik wil wel dat als ik voor die auto betaal, dat ik er wat aan heb. Anders blijf ik wel in mijn huidige auto rijden

S: Ondertussen zijn er weer 5 minuten versterken.

C: Maar men kan toch wel tegemoet komen op de tijd? 3, van ons alle 3 eentje. Wat vindt jij dan belangrijk?

OV: Doorstroming.

NC: Doen we die er ook nog een.

C: Ben ik tevreden. NC: alleen AF maakt het geen donder uit. AF: Nee inderdaad.

AF: Dan wil ik wel wat op aansprakelijkheid. Maar dan wel op iemand anders.

NC: Op jou! ,...of een verzekeraar.

AF: al moet men dit wel hebben voordat iemand het gaat kopen.

NC: Doen we er nog een paar op. Gebruiksvriendelijkheid en zelfbeschikking krijgen we nog.

AF: omdat ik het een moeilijke term vindt. (het wordt voorgelezen)

NC: Aha, dus AF kan er anders geld aan verdienen.

S: Of Overheid kan bijvoorbeeld mensen sturen over het netwerk of zorgen dat je maar 120 mag en bij wegwerkzaamheden maar 50.

NC: Het is dus alleen voor de gebruiker interessant. Voor de rest niet.

C: Ik vind het raar dat dit zo onderbelicht wordt. Ik koop dat ding niet als online staat waar ik gereden heb.

AF: Ok. is goed. Fiche. Dan mag er ook een op gebruiksvriendelijkheid.

OV: ja, das wel een beetje ons gemeenschappelijk doel. Doen we er daar ook nog wat. Okee, nu gelijkwaardigheid.

NC: Wat vind jij daarvan als overheid?

OV: nou, niet perse. Als er ideële doeleinden bij horen wil ik het wel subsidiëren. Doen we ook met zonnepanelen, maar ik ga niet alles subsidiëren.

NC: komt er een tijd dat men gaat stimuleren om ZRA te denken.

OV: Ver vooruit kijken vind ik lastig. Maar uhhh, wat denken jullie?

AF: Men de-stimuleert ook om oldtimers te gebruiken, das ook geen gelijkwaardigheid.

NC: onze tijd is trouwens een beetje op. C: ok, alles op veiligheid. AF: nee beveiliging. C: ik wil ook lage bijtelling. NC: ok, maar keuzes maken. C: Veiligheid.

-------------- Pauze ---------------

C: Wat ik heel erg merk, sommige hebben een stelling met voor of tegen gekozen is. Je kan niet anti-stemmen. Ook aansprakelijkheid.

AF: Sommige zijn erg duidelijk, meer veiligheid wilt iedereen, maar meer aansprakelijkheid is wel lastig. Dat zegt weinig.

C: De kant op waar die op geformuleerd is maakt het voor de ene partij aantrekkelijker dan voor de andere. Beetje lastig.

S: Ja, je kan hem 2 kanten op goedpraten. Beste voorbeeld is zelfbeschikking, die kan echt 2 kanten op.

C: ja inderdaad.

------ Pauze ------------

Step 2: specification from values to norms

S: Zullen we door met de volgende stap. De volgende stap is om deze vage aspecten iets concreter te maken. Die wordt in de literatuur waarden genomen, en 1 stap concreter worden normen. En als je nog 1 stap concreter gaat worden dat echte dingen zoals bijvoorbeeld wetten, maar in de techniek worden dat 'design requirements'. Dus, wat we gaan proberen is om de waarden te specificeren naar de normen. Om een voorbeeld te geven. Stel je vindt duurzaamheid belangrijk.

AF: zit die erin trouwens?

S: Ja bij doorstroming. NC: Oh, dat kon misschien duidelijker. AF: Had het sustainability genoemd, dan was er meer op gestemd. NC: Greenwashing!

S: stel je zou duurzaamheid zou je specifiëren naar X CO2 per km, en X benzine. Ga je nog 1 stap verder dan kies je welke banden er gebruikt moeten worden. Die laatste stap gaan wij niet doen, dat is aan de autofabrikant. Het zou mooi zijn als we op normen komen die in .. uhh C: in SI eenheden zijn. S: haha, ja ongeveer, het is dus niet beter piano kunnen spelen, maar dat je zegt dat je Chopin wilt kunnen spelen over 1 jaar.

NC: Kwantificeren. AF: SMART? S: nou niet helemaal smart, maar als we het maar aan iets absoluuts kunnen relateren. NC: Absoluut, niet per se kwantitatief. S: Ja, bijvoorbeeld 2x zo goed als ... mag ook.

S: Het handigste is om het uit te splitsen en dan die aspecten te gaan scoren.

C: Dus dit is de Parijs klimaat top voor ZRA?

NC: Een manifest schrijven dus.

S: We gaan ze waarschijnlijk niet alle 8 redden, maar zullen we met de grootte beginnen?

Specificeren

NC: ik denk meteen aan andere deelnemers in het verkeer. Het moet minimaal net zo veiliger.

I & C: veiliger!

AF: Wat is veiligheid? Misschien hoeveel ongelukken per jaar? Wat voor KPI zijn er?

S: Daar zal ik even bij helpen. Het aantal doden, ongelukken of zwaar gewonden.

NC: Minstens 50% naar beneden.

AF: Doden vooral, kleine ongelukken minder.

NC: das het ding met veiligheid, je kan er niet tegen zijn.

OV: Maar wel minder belangrijk vinden.

AF: net gezegd waarom we dit belangrijk vinden, en nu hoe?

S: Ja, eerst heeft iedereen zelf in de enquête zijn eigen utopie gemaakt, toen hebben jullie er samen een gemaakt, en nu mag het iets concreter.

NC: de normen voor veiligheid moeten dus ook veiligheid als we dat belangrijk vinden.

AF: Het wordt dus wel moeilijker om voor mij bij elk punt om het op de weg te krijgen.

OV: We kunnen het alleen relateren aan auto's nu dus? 20% minder ongelukken.

C: Kun jij zeggen dat het 0 wordt?

OV: Je hebt interne veiligheid van de inzittende en extern dat naar beneden gaat, en misschien vinden mensen het ander belangrijk.

NC: Maar mensen die in een auto zitten lopen ook wel eens, dus vinden misschien dat ook wel belangrijk.

AF: Moeten we nu gewoon met een getal komen van zoveel veiliger?

S: ja bijvoorbeeld 2x zoveel.

C: maar eist de overheid dan niet 0 ongevallen?

OV: Ik kan dat zeggen, maar das wel onhaalbaar. Kun je dit trouwens wel relateren aan wat er is? Want je weet niet hoe veel er zijn?

C: Ja kan, dan zeg je dat 1 zoveel veiliger moet zijn dan een ZRA.

NC: Je neemt gewoon een gemiddelde par auto. Bijvoorbeeld 2x zo veilig. Alleen wordt het voor andere auto's dan niet juist moeilijker?

S: Maar je kan wel zeggen 'het verkeer moet 2x zo veilig'.

NC: alleen weet je dan niet het %?

AF: Of gewoon 'ongelukken door zelfrijdende auto's moeten zoveel % lager zijn".

J: Doen we dan 50% minder?

C: dat kan wel nog minder denk ik. Nihil door ZRA.

NC: kan dat?

C: Ja, maar dan is het niet zijn schuld.

AF: Maar stel er valt een boom op de weg en je hebt 2 keuzes. Uitwijken en een kind aanrijden of crashen.

C: Ok, ja, dat klopt ja. Wat moet je dan doen? (even heftige discussie over het ethisch dilemma).

OV: Ok, maar dus veiliger.

S: Ik hoor mensen zeggen de helft, of 20% of wat?

AF: Ja een getal noemen is lastig. Ik denk 10%.

E &NC: 5%! C: Het gaat alleen met zo weinig ongevallen toch niet statistisch te onderzoeken zijn. Daar gaat het CBS moeite mee krijgen. Als je dan 1000 auto's hebt heb je 1x in de 10 jaar een ongeval.

AF: Het CBR gaat hier trouwens ook moeite mee hebben.

NC: okee dus bijna nul. Het is dus mimimaal 5%. Of maximaal, anyway?

S: En maakt in of buiten de ZRA nog uit?

AF: Het ervoor springen?

S: Nee, maakt het voor de veiligheid uit of het voor de inzittende of voor andere gaat?

C: neu, iedereen is gelijk.

AF: Mij maakt het niet uit, ik ben in ieder geval blij dat het niet nul is, dat is echt onmogelijk voor mijn technici.

Mogen we dan nu de volgende doen? S: ja welke willen jullie? AF: Beveiliging. S: Top

OV: Welke aspecten hebben we binnen beveiliging?

NC: Lastig te hacken, te stelen of de misbruiken

AF: Stelen is niet meer te doen. Okee, misschien altijd mogelijk.

NC: Hoe meer geautomatiseerd is hoe moeilijker. AF: Fingerprints enzo. NC: Hacken is dus besturing overnemen, of jatten. S: Hacken kan 2 kanten hebben: het echt overnemen, of datadiefstal of identiteitsdiefstal.

NC: Echt terrorisme dus.

C: Of er drugsdeals mee doen 's nachts. (lol over drugsdeals en discussie of je coke wel of niet ruikt in je bekleding en suzuki swifts).

OV: Je kan hem wel makkelijker terugvinden. S: Ja, tesla kam auto's terugvinden en volgens mij ook onbruikbaar maken. (lol om tesla jatten en hoe hem terug te krijgen)

C: maar ik vind best het bedrijf van AF betrouwbaar, maar dan komen er een paar Chinezen op de markt en dan?

AF: Ja, nu zijn ze niet te hacken, dus hoe kunnen we dit relateren.

C: Al kan je ze nu ook zetten.

S: Ja, hij is inderdaad lastig te kwantificeren.

NC: We kunnen wel net zo moeilijk te hacken zijn als dat auto's nu te stelen zijn. AF: Of op het niveau van hoe banken nu beveiligd moeten zijn. C: al is dat ook niet helemaal te vertrouwen.

OV: er moeten sowieso regels voor komen. Zijn die er al?

S: Euro NCAP voor botsen, maar voor hacken of stelen niet.

NC: Het nare is dat je niet nu alleen iemand auto hebt, maar echt in zn privé sfeer kan duiken.

AF: Je kan ook de besturing open source maken. (discussie over opensource, autosoftware op de piratebay)

OV: Ja, maar ik heb net als spoilers geen zin in rare software.

C: Ik denk dat normen voor banken het handigst is.

NC: De zin "Een auto hacken moet net zo makkelijk zijn als het kraken van een bank" klinkt heel raar. Bijna reclame.

AF: En er moeten sowieso wetten komen. ZRA specifiek. Er is nog niks, en dit moet om het te laten slagen.

C: Dus een controle met encryptienormen met evt boetes. (discussie over boetes)

AF: Is data diefstal en overnemen hetzelfde beveiligingssysteem.

C: Ja ik denk t.

AF: al is het wel echt anders als je kunt zien dat men het over kan nemen, dan moet je er echt diep in zitten. Je kan ook even coockies tracken. Das meer shady...

C: er moet sowieso een wet komen.

AF: En dus industry level security. En dat als maatstaf nemen.

S: Dus weer geen 0 maar nihil.

S: en jullie hadden het over stelen.

AF: ik denk dat die regels hetzelfde als nu kunnen zijn: ze mogen niet gejat worden.

S: ja maar wat wil je.

AF: Ja zo min mogelijk

C: Ik vind dat auto's zijn traceerbaar, dus de autofabrikant is verantwoordelijk om hem terug te vinden. Of om een nieuwe aan te leveren. Hij weet per slot van rekening waar die is.

OV: Dus niet jij bent degene die hem terug moet vinden, of de politie, maar de autofabrikant.

AF: Ik ga er toch voor zorgen dat die dingen niet meer gestolen worden.

C: Maar garandeer jij mij een nieuwe auto?

AF: Mm, nou ik zoek hem gewoon terug.

C: ik snap wel dat dat interessant is, want als een bank bijvoorbeeld gehackt wordt, dan geeft de bank het gestolen geld terug. Nu kan dat ook zoiets zijn met een auto.

AF: Ik kan het niet uitsluiten dat het mogelijk blijft om te jatten, maar wel echt sterm omlaag te brengen.

OV: Ik schrijf dan op dat autofabrikanten verantwoordelijk worden/

C: ik kan dat ook van Apple voorstellen, dat zij dan je Iphone gaan terughalen.

OV: deze is dan wel mooi zo.

S: even pauze? C: nee het voelt al ongeveer als

(NC gaat weg om telefoongesprek te houden)

S: We kunnen doorstroming doen, maar het zou wel fijn zijn als NC daarbij is

C: Heb je geen kritieke massa nodig voor dat er voordelen zijn?

AF: Ja, of een zelfrijdende autobaan. OV: Autobahn!

AF: en er is ook nog iets met duurzaamheid.

(Discussie over hoe ZRA's de doorstroming beïnvloeden. Na 2 min discussie wat uitleg van de facilitator afstand houden)

C: het ministerie heeft bijvoorbeeld belang. Die hoeven minder wegen aan te leggen. En economische voordelen.

AF: Maar moet ik dan overal dingen in gaan bouwen.

C: Ja als het doorstromingsvoordeel heeft wel. OV: ja inderdaad. Daar kan ik eisen van maken.

AF: Maar ik moet dan overal inbouwen. Ook in nieuwe?

C: Ja bijvoorbeeld na 2018 moet het ingebouwd zijn, ook in niet ZRA.

AF: Dit is voor mij echt alleen maar a-relaxed. Dus niet-ZRA auto's krijgen een feature om het makkelijker te maken om ZRA op de weg te krijgen. Dat vind ik raar.

C: Maar het kan ook de verkeersveiligheid ten goede komen.

AF: Maar das niet communiceren.

C: Maar dan geven ze door dat ze remmen.

S: Okee, maar vinden jullie dat een ZRA moet zorgen voor minder file?

I & C: Ja.

C: Maar het kost wel geld natuurlijk.

AF: maar mag minder doorstroming ook? Ze komen er toch wel en dan lossen ze het daarna wel op...?

OV: Ja, een beetje meer mag wel, maar niet te veel en het moet dan wel harder doorstromen daarna.

(Discussie over zelfrijdende auto en snelheidsboetes)

AF: misschien mag het niet slechter zijn voor de doorstroming, dat lijkt mij raar.

C: of we moeten investeren in als het slechter is voor de doorstroming.

AF: Mag niet slechter worden!

I : Misschien mag het wel tijdens testen slechter zijn voor de doorstroming maar daarna niet meer. (aandacht verslapt en discussie gaat over testen van auto's)

C: maar we hebben dus communicatiesystem nodig, maar ik hoef dat niet te verplichten aan het begin.

AF: doen we bij een APK erin. En dan betaalt de overheid die.

OV: Als het zich terugbetaald of dan wel.

Transsript workshop 2

8 januari 2016, 15:00, TNO

S = Steven   Facilitator / researcher
O = Overheid   Government, student Transportation & Planning
NC = Niet consument   Non-consumer, graduate TU Delft
C = Consument   Consumer, student TU Delft
AF = Auto fabrikant   Car manufacturer, ex-intern Tesla / student TU Delft

Introduction: deviding points solo

<S legt doel uit "samen tot een compromis te komen en pijnpunten onderzoeken", en geeft introductie in zelfrijdende auto's van level 3 en spreekt de waarden door met alle deelnemers>

S: We beginnen met een de enquête maken, maar dan met z'n 4en in plaats van alleen. Mijn voorstel is om een voorstelrondje te doen en dat iedereen meteen de fishes op de de plek legt <iedereen heeft er 10 gekregen>

O: Ik ben de overheid, je kan het beste denken aan RWS of het ministerie van I&M. Ik vind het belangrijk dat er minder files en minder ongelukken gebeuren. Ook minder uitstoot, maar dat is aan files gelinkt hier. De rest is leuk en aardig, maar minder van belang.

S: zijn er nog andere dingen, die misschien minder van belang zijn?
O: Bijvoorbeeld beveiliging, maar die vinden denk ik de andere belangrijker. Bijvoorbeeld de autofabrikant of de gebruiker. Ik zit hier voor de veiligheid en minder file. Dit zijn mijn twee speerpunten.
NC: Ik wil wel, maar heb nog niet exact bedacht wat ik wil.
S: Je mag halverwege ook even wisselen als je iets over het hoofd ziet.
NC: Ik heb er wel een beetje over nagedacht. Ik wil graag dat het veilig is, en ook dat ik dat kan inschatten. Ik wil weten dat zij mij hebben gezien.
S: Wat je nu noemt staat er niet helemaal tussen, maar dat past erg mooi in het tweede deel. Dan specifiëren we veiligheid verder. Dus ga er nu maar vanuit dat het veiligheid is.
NC: Ik zal hem onthouden. En ook wat op aansprakelijkheid. Ik wil weten wat er dan gebeurd.
O: Geen punten op gelijkwaardigheid?
<zelfbeschikking wordt verduidelijkt>
NC: Ok, minder zelfbeschikking misschien en meer gelijkwaardigheid.
AF: Ben je niet nu te tegen zelfrijdende auto subsidie.
NC: Ja, misschien inderdaad. Ik vind het niet erg als ze een beetje gesubsidieerd worden, maar niet erg veel.
S: Bij al je fiches erop dan wordt er geen geld uitgegeven, maar zo wel een beetje, maar onder voorwaarden. Dat maak je nu goed duidelijk.
AF: Ik vertegenwoordig autofabrikanten. Wat ik vind hangt een beetje af van de definities die wij vinden. Ik vind veiligheid sowieso erg belangrijk. Het aantal ongelukken moet stukken kleiner zijn. Veiligheid voert de hoofdmoot. Sommige dingen zijn belangrijk voor de gebruikers en minder voor mij, maar daarom wel belangrijk voor de acceptatie. Zoals tijd anders gebruiken bijvoorbeeld. Dat is meer een punt van marketing. Als aansprakelijkheid gedefinieerd is als dat het niet bij de bestuurder ligt weet ik niet wat ik vindt. Als het duidelijk geregeld is kan ik het er alleen maar mee eens zijn.
S: Dat is ook iets voor het specificeren. Leg er misschien dan maar een fiche neer, maar niet alles.
AF: Ik wil ook wel iets met beveiliging. Al hangt het niet pre se met zelfrijdende auto's samen. Je kan ook niet zelfrijdende auto's hacken. Zie bijvoorbeeld de jeep. Misschien is dit meer iets voor de overheid. Ik let er altijd op, maar nu niet extra. Verder is gelijkwaardigheid niet belangrijk. Gebruiksvriendelijkheid en zelfbeschikking zijn ook fijn, mag een klein beetje op, voor de acceptatie. Als er meer vertrouwen is mag de zelfbeschikking om laag.
C: De toekomstige eigenaar van een zelfrijdende auto. Veiligheid vind ook ik belangrijk. Dit is de hoofdreden dat we hier mee bezig moeten zijn. Ook milieu en doorstroming vind ik belangrijk. Dat kan misschien nog niet helemaal, maar vanuit mijn perspectief is toch veiligheid. Daar komen er 4. Ook aansprakelijkheid. Ook een paar bij tijd anders gebruiken. Gelijkwaardigheid is niet belangrijk. Zelfbeschikking is een beetje belangrijk, het is niet doorslaggevend. Als ik met de trein reis heb ik dat ook niet. Daarmee kom ik ook van A naar B.
Rond 1: deviding points together

S: Nog aanpassingen? Dan gaan we door naar de volgende. Jullie krijgen nu 80 fiches, en jullie mogen het samen uitzoeken. <stilte en gelach>

S: Dus samen tot consensus komen, en als dat niet lukt dan is dat ook een resultaat.

NC: veiligheid is sowieso veel.

AF: Ja, daar moet de helft van de fiches heen. Daar zijn wij het denk ik over eens.

NC: misschien wel gek, doordat iedereen daar geld op inzet sneeuwt de rest enorm onder.

C: ook aansprakelijkheid daar liggen ook veel fiches.

C: Bepaalde overlappen maken het wel lastig. Veiligheid en tijd anders gebruiken of beveiliging liggen samen.

< uitleg over het spel en daarna discussie over veiligheid>

NC: we verdelen nog 40 punten.

AF: Ik kan me best eens zijn met iedereen die twintig fiches geven en die zelf verdelen.

NC: Nou, we moeten best overleggen, en sommige mensen zijn ook tegen iets.

AF: Ja. Een conflict wat we moeten oplossen is bijvoorbeeld gelijkwaardigheid. Sommige zijn positief en andere negatief geformuleerd.

S: Ja klopt, sommige vindt iedereen belangrijk en andere zijn meer een dilemma.

NC: ik heb er als andere consument ook baat bij doorstroming. Als andere mensen gaan carpoolen heb ik daar voordeel mee.

O: Dus een stapeltje bij doorstroming en bij aansprakelijkheid.

S: En hoe denken jullie over tijd anders gebruiken.

O: dat is eerst gewoon een bonus voor de bestuurder, als je je tijd anders wilt gebruiken ga je maar met het OV.

C: dat is natuurlijk niet helemaal hoe het werkt. Het duurt 2x zo lang.

<uitleg over zelfbeschikking, "de meest extreme vorm is dat je bijvoorbeeld niet mag rijden omdat de overheid heeft bepaald at er te veel auto's op de weg zijn">

AF: zou de overheid dat niet juist ook belangrijk vinden dat men de tijd anders kan gebruiken, economie enzo?

O: Nou, niet onbelangrijk, maar de rest belangrijker.

NC: Maar EZ kan bijvoorbeeld het wel belangrijk vinden.

O: Ja klopt, maar dan is doorstroming nog beter, dan kan iedereen het doen en uitstoot kost ook veel geld. Het is echt een bonus.

O: de andere fiches verdelen over gelijkwaardigheid en zelfbeschikking.

C: Als zelfbeschikking verkeerd wordt aangepakt gaat het fout. Dan krijg je een tegenreactie. Je moet een keuze erin hebben.

NC: De eindgebruiker wil een keuze kunnen maken.

C: Als dit in een klap veranderd schik je mensen echt af.

NC: Het zijn twee kanten. Vrijheid en data. Dus privacy.

AF: Mag je de backbox uitlezen en mag je zelf bepalen hoe hard je rijdt. Het valt net niet onder de juiste noemer. Het zijn nu twee dingen in 1 aspect.

S: Ik hoor al dat jullie de volgende stap boeiender vinden dan deze, dus misschien zo snel door. Lukt het nog om de punten te verdelen?

AF: Ok, wie heeft er iets op tegen als ik er hier 10 neer leg. O & NC: Das wel te veel.

NC: Wil je als overheid echt gelijkwaardigheid, want je gaat dan dwingen wat mensen moeten doen.

AF: Dat is toch wel wat een overheid doet..?

O: Het moet veilig zijn en snel doorstromen dus.

AF: ik wil juist niet hier fiches, maar een paar mogen misschien wel.

C: Ik stimuleer gelijkwaardigheid liever niet, maar 1 fiche moet kunnen.

S: Ik merk dat het nog langzaam gaat, misschien is het goed als 1 iemand kijkt wat hij een beetje proeft in het algemeen en dat dan de rest daar commentaar op geeft.

NC: Aansprakelijkheid is iets belangrijker dan zelfbeschikking, dus er moeten er misschien nog een paar verplaatst worden.

C: Ook daar zit weer overlap. Die data kan weer gebruikt worden. Het blijft verweven. En of de overheid heen kan. En mag dat als een moord is gepleegd en er staat een auto op het plaats>

O: gebruiksvriendelijkheid heeft niks, daar mag bij. NC: en dan hier ook wat. O: De meeste vindt dat toch belangrijk denk ik.

C: Hoe zit het met gebruiksvriendelijkheid dan.

AF: Wat wordt er dan bedoeld met iedereen? Als je iedereen vertegenwoordigd dan moet je ook die mee nemen.

S: Je hoeft het niet zo extreem te zien hoor.

NC: Je discrimineert bijvoorbeeld naar hoogopgeleiden. De eerste computers. Die waren niet gebruiksvriendelijk, nu kan iedereen er mee.

S: Ja wil, je DOS of de IPad?

AF: Hier ligt nog niks van de overheid. Een blinde man kan dan ook reizen. ZO heb je minder sociale uitsluiting.

S: Ik moet er wel bij zeggen dat je een rijbewijs hebben...

AF: Fair enough, dan werkt het nog niet nee.

S: Maar je oma kan er wel mee. Zonder vingers kun je zowel geen DOS als geen IPad besturen, maar als je ouder bent is de IPad wel echt makkelijker.

S: Misschien iets met de 40 van de veiligheid?

C: daar zijn we het wel mee eens. Misschien is 30 wel genoeg.... Dan is het nog steeds duidelijk de meest belangrijke.

AF: Ik zou mijn fiches ook allemaal op veiligheid zetten. Want zonder dit valt alles uiteen.

<S vat de volgorde samen van punten>

NC: Ja, klopt alleen niet helemaal.

C: De tijd anders gebruiken is iets belangrijker. AF: en beveiliging is nog een beetje een ondergeschoven kindje. omdat ook misschien de overheid daar nog wat op wilt hebben.

O: Ik wil er best regels voor maken, maar jij mag het maken.

NC: Misschien ook wel toezicht. Het wordt helaas niet altijd gedaan nu, maar mag meer.

S: als je geen punten geeft zijn er geen regels en kan alles loslopen. Iedereen kan het op de markt brengen.

AF: Nu geeft de RDW een typegoedkeuring.

S: Misschien is het goed om met fiches te praten, daar dienen ze voor.

AF: Ik kan me er in vinden, behalve in beveiliging vs gelijkwaardigheid.

C: Ik wil niet gehackt worden. Dat wil ik niet. Men moet er niet in kijken.

O: Ik zou meer denk aan stelen. Er mag niet ingebroken worden. Niemand mag erin komen. Dat ligt bij de fabrikant. Die controle kan ik doen.

S: Klopt, maar het gaat er nu om wat je belangrijk vindt en niet wat er in je macht ligt.

C: Ik zou nooit een auto zonder slot kopen. Dus beveiliging. Hier leg ik er dus 3 bij.

AF: Dat wil juist de overheid denk ik. Het wordt niet geaccepteerd dan.

NC: Heeft gebruiksvriendelijkheid niet te weinig. Ik vind het niet zo boeiend, maar jullie..?

AF: Het hoeft nu niet, ik wil dat later best, maar nu maakt het niet zo veel uit. Ik hoef geen marktaandeel wat nog groter is door 80 jarigen die bijna van de markt af gaan.

<S vat het opnieuw samen, "is dit wat jullie willen?">

S: kan iedereen zich erin vinden in wat er ligt. Zou jij dit bouwen?

<Discussie over wat voor fabrikant AF is. Conclusie: je bouwt ook normale auto's, maar bedenk wel dat je miljarden hebt geïnvesteerd in ZRA>.

S: Zullen we dan even pauze houden en door naar de volgende stap.

PAUZE:

Discussies in de pauze:

- Sommige punten hebben relaties. Niet helemaal Mutualy excluisive.

- Milieu mist, maar blijkt bij doorstroming te zitten.

- Sommige waarden hebben relaties.

- De meeste discussie was over: (vraag van Steven): zelfbeschikking, gelijkwaardigheid, misschien aansprakelijkheid

Round 2: specification of the values to norms

S: We beginnen met een makkelijke: veiligheid en dan zelfbeschikking.

<uitleg over waarden en normen. Eerst opsplitsen en dan "end-norms" maken>

<S schrijft, de rest staat om de flipover, ruimte wordt verbouwd>

C: categoriseren dus.

S: Ja, laten we er 2 uitwerken.

AF: Ja, verkeersdoden. O: en misschien materiële schade. NC: Ernstig gewonden? Of licht. Of blikschade.

C: ook voor inzettende of andere?

AF: Als koper vind je het misschien belangrijk dat je zelf nog leeft na een ongeluk. NC: Ja we kopen allemaal een hummer en een SUV.

<Trolley dilemma wordt besproken>

S: Zullen we van de doden een end-norm maken?

AF: We hebben het over level 3. 10 x minder doden.

NC: Wat is het meest terug te dringen? Is doden niet makkelijker dan ernstig gewonden?

C: Zijn niet ook sommige type ongevallen makkelijker te voorkomen dan andere?

S: Misschien goed ter verduidelijking: je mag utopisch denken. Het hoeft niet praktisch haalbaar te zijn, althans niet onhaalbaar. Auto's moeten vliegen, kan niet. Maar als jullie zeggen: 'ik wil niets anders dan 0 doden' dan kan dat.

NC: 0 gaat wel erg ver. Het moet sowieso veiliger zijn.

C: Minder directe aanrijdingen.

AF: Het is echt active safety. Hij gaat voor je remmen.

NC: of in ieder geval minder gewond.

S: misschien iets van het praktische af. AF noemde dat het 10% van nu wordt. Bedenk je dat het of duurder wordt als je hogere eisen stelt, en dat het langer duurt voor ze er zijn. Waarschijnlijk zelfs beide. Dat is de afweging die je moet maken.

AF: 10x bedoel ik dat die auto minder betrokken is. Als alle auto's zo zouden zijn is er 10 % over.

NC: 10 is prima. klinkt ook lekker makkelijk. Alles hoeft niet en is lastig.

C: Voor ernstig gewonden ook.

NC: betrokken is nu lastiger misschien. Je moet dus compenseren voor als de wederpartij geen ZRA is. Dat de schuld minder is kan.

AF: zelf zie ik niet echt het onderscheid tussen de verschillende schades. Het zijn dezelfde technieken.

S: En verschil tussen in en buiten de auto?

NC: ik denk dat je het voor andere vooral veiliger maakt.

S: Maar wat wil je?

C: Er gaan amper mensen achter het stuur dood. We moeten juist andere mensen helpen.

NC: ja klopt, tenzij je op een vrachtwagen botst.

S: dus waar moet de focus.

C: Ik denk andere. Naar inzittende is het al best prima. Zelfrijdend op zich is niet per se voor inzittende meteen veilig.

AF: Het zal vooral en-en zijn. Je redt aan 2 kanten de levens. Je focus op niet inzittende is belangrijk omdat die de zwakkere zijn.

S: Dus een focus op zwakkere.

C: Ja stel het zou om een ZR-vrachtwagen gaan, dan zouden we allemaal voor andere gaan.

NC: inzittende bijvoorbeeld 2x veiliger, en andere 5x veiliger.

O: en ongelukken voor ZRA moeten echt nihil zijn.

NC: Ja 0 is zo weinig, maar bijna 0.

S: das minder dan 10%, maar kan.

R: Nihil dus tussen 2 ZRA.

<Discussie over hoeveel marktpenetratie en veiligheid is>

C: gaat het trouwens om Nederland?

S: Ja klopt, dat is beter.

<grappen over Turkse en Belgische wegen>

S: zullen we een moeilijkere doen: zelfbeschikking.

AF: Hier moeten we denk ik meteen gebruik van data en autonomie maken.

S: privacy en autonomie, zal ik ze zo noemen.

AF: Autonomie is wat lastig in deze context misschien, autonomie van de autonome auto. Maar, iedereen was er bij toen het bedacht was, dus dat kunnen we uit elkaar houden.

C: Is het soeverein?

NC: Of zeg je dat alleen maar van landen?

S: wat moet er onder privacy?

C: Als het volledig bij de koper ligt dan is dat een stimulans. Als de koper niet mag beslissen dan wil men het niet. Dat demotiveert de innovatie.

S: Dus je denkt dat de auto geen data moet doorsturen.

C: Ja, en bij meer acceptatie kan het.

NC: Lig er aan waar het voor gebruikt wordt. Google maps wordt ook verbeterd op basis van je data.

AF: ik denk dat transparantie belangrijk is. De eigenaar moet weten wat er doorgestuurd wordt. Een deel van de data mag niet zomaar in andere handen vallen. Voor een deel is het van belang dat het in bezit van de fabrikant komt. Of dingen met de belasting dienst.

<korte discussie die door elkaar heen loopt over opsplitsen in reclame, in navigatie, politie, opsporing of verbetering van de auto>

C: Of de mede eigenaar. Je bedrijf of je vrouw? En onderhoud?

O: Overheid crimineel, of niet crimineel. Belasting en justitie, en de rest is dat ze zien hoeveel file ergens is.

AF: dan moet je misschien achteraf of vooraf bekijken bij justitie. Ze kunnen toedracht van een ongeluk herleiden, en daarmee een misdaad oplossen of dat ze meteen monitoren/

S: zijn dit stellingen om het even over te hebben?

NC: Verbetering en onderhoud mag van mij best veel data.

C: daar zal niemand tegen zijn.

NC: geanonimiseerd is algemeen. Je stuurt dus je crash report bij je browser.

AF: Maar mag je ook jou een email sturen als het om jou auto gaat. Dat kan je niet anonimiseren.

<discussie over hoe bedrijven met data omgaan>

NC: laten we er vanuit gaan dat niemand het misbruikt. AF: al is dat wel gevaarlijk.

C: zolang ze maar niet op afstand m'n auto uit zetten.

S: misschien opsplitsen in wat je verplicht moet afstaan en wat men mag kiezen. En evt wat sowieso niet.

C: Verbetering verplicht, net als justitie. Dat maakt het veiliger. Dat hebben we veel punten gegeven.

NC: Justitie is wel moeilijk. Je hoeft niet jezelf in kwaad daglicht te stellen, je moet geen bewijs verzamelen tegen jezelf. Er moet eerst een verdenking zijn.

C: Dus niet sowieso.

S: dus monitoren en achter.

NC: ja monitoren is stuk minder fijn.

AF: Dit staat los van het zelfrijdende zijn. Dit gaat om alle auto's die met een internet verbinding. Die kunnen ook al doorgeven of ze zonder verzekering rond rijden. Dat gaat meer over slimme auto's dan zelfrijdende auto's.

S: Laten we die er meteen bij nemen. De communicatie onderling gaat alleen over locatie. Zodat men niet botst.

AF: Die reclame. Gaan we het daar over hebben.

NC: het moet in ieder geval een keuze zijn.

AF: Zou het een keuze zijn?

C: Navigatie trouwens altijd doorgeven toch. Allen: ja

NC: justitie achteraf ook bijna altijd wel. C: Je wilt dat ook altijd, want anders gaat de fabrikant het niet vergoeden en heb je het zelf gedaan.

S: Reclame, wat vinden jullie. NC&C&O: keuze. AF: ik zou zeggen nooit, maar dan ben ik misschien ouderwets in.

NC: Ik wil het niet, maar vind het prima als andere het doen.

AF: persoonlijk heb ik een grafhekel aan reclame. Als fabrikant de broker wordt van de informatie. Dat lijkt mij een raar businessmodel. Als autofabrikant vind ik het prima, maar het wordt wel allemaal heel anders. Maarja ze verdiende het ook nooit met zelfrijdende auto's, dus misschien ook ooit met reclame. Als klant zou ik dat niet willen. Net als ING die aanbiedingen wilde laten zien. Daar wilde men ook dat ze een bank bleven.

NC: Daar was alleen geen keuze.

C: Je kan reclame ook zien als nuttige informatie: waar is een tankstation of hoe moet ik reizen.

S: Laten we nu even bedrijven noemen, en anders is het navigatie.

C: blijkbaar zijn er mensen die bonusaanbiedingen kijken, die willen dit misschien ook wel dit.

O: Ik zou het ook nooit gebruiken, maar men mag het doen.

S: En zoiets als 5000 euro korting bij aanschaf, maar wel altijd reclame. Is dat een prima businessmodel? Hij kan niet uit.

AF: Met geluid, heel hard. En eye tracking, anders telt het niet. Het punt wat ik wil maken is dat het hek van de dam is.

NC: als de keuze wordt aangeboden dan is het prima.

AF: Ik wil niks ongevraagd aangeboden krijgen, althans soms misschien. Maar de rest hoef ik niet.

O: maar dat gaat sowieso vorkomen.

AF: Maar ik heb nu een auto zonder reclame. Ik heb nu trouwens meer de rol van automobilist, maar ik wilde even de andere kant verdedigen.

O: Ik wil geen afleidingen tijdens het rijden. NC: maar men rijdt niet zelf. AF: als fabrikant zeg ik alles waar ik geld mee kan verdienen is prima. NC: misschien kunnen zo wel meer mensen een auto kopen. Een oude auto zonder reclame of een BMW met. net als met gratis apps.

S: Dus samenvattend. Keuze / liever niet. C: maar iedereen hier geeft ook meteen aan het niet willen.

O: er zijn gewoon mensen die het misschien wel willen.

AF: ik had eigenlijk niet verwacht dat ik een uitzondering zou zijn.

NC: haha, nee, we willen dat allemaal zelf ook niet.

S: Ok, monitoren. Justitie kan dan online zien of per dag dat je zonder verzekering en of te hard. Dus zonder verdenking kunnen ze zoeken.

NC: keuze is hier een hele lastige optie. Dus dan zou ik voor nooit gaan.

O: ik wil alles zien. NC: vanuit mijn rol boeit het mij niks trouwens. C: vanuit mijn rol wil ik nooit, dan kan ik doen wat ik wil. AF: Misschien dat andere eigenaren iets doen wat jij niet wilt. C: dat er geen onverzekerde naast mij rijden, waarvoor ik misschien opdraai.

S: Als je geen verzekering hebt staat er morgen politie op je stoeptegel.

NC: dat gaat erg tegen de autonomie in. Zonder verzekering gaat je auto niet aan. Of met schuld bij de belastingdienst.

O: is wel het beste voor de algehele veiligheid.

NC: is wel heel technocratisch.

S: C, wat denk jij? Misschien moeten we C even helpen?

O: het wisselt per persoon. Misschien wilt opa het wel, maar als je net je rijbewijs hebt niet.

AF: moet de overheid dit juist ook zeggen niet te gaan doen aangezien je dan de-stimuleert dat ze komen.

NC: Je levert heel veel vrijheid in. Big brother watching you. Dus nooit.

AF: conservatief.

NC: ja, of vrijheid....

S: achteraf. mag wel dus.

C: Ja. zeker. bij een ongeluk ofzo wel.

S: en Rijkswaterstaat mogen die zien waar hoeveel auto's rijden?

C: Ja, dat vind ik prima, dan kan men doorstroming verbeteren.

NC: een soort van verbetering, maar dan niet aan de auto maar aan de wegen.

S: En is het dan altijd of keuze.

O: Anoniem of altijd?

AF: ik denk dat sowieso anoniem.

<uitleg over wissen eerste en laatste kilometer. Alleen N-wegen tellen is de uitkomst>

S: en dat is dan een keuze.

O: is dat niet lastig qua statistiek.

AF: volgens mij weten de slimme jongens daar wel iets over te vinden.

S: je kan het vergelijken met tel lussen in de weg.

NC: voor de acceptatie is keuze denk ik beter. Anoniem en niet te herleiden. Dus niet op jouw landweggetje.

AF: en de leasemaatschappij en andere in een huishouden. Kan dat ook?

S: Leuke ja, die moeten we nog.

C: Wat wil de baas? Die wil graag alles zien denk ik.

AF: Zou jij als baas willen weten wat die mensen met de auto doen?

NC: wel als jij een sluitende kilometeradministratie moet hebben.

O: of als er rare dingen gebeuren.

C: Het aantal KM is nog niet zo interessant, dat kun je nu ook. Het gaat meer om waar en hoe wordt er gereden.

AF: waarom zou je dat willen weten?

C: Dat er geen privé km gereden wordt.

AF: dat kan je nu toch ook. Das best simpel te doen.

S: Er zijn ook bedrijven die dat gewoon toestaan, met tankpas zonder registratie.

NC: Das waar, maar er zijn ook bedrijven die dat graag niet hebben.

AF: en waar leven die data? Is dat op een harde schijf. In de overheid cloud? De ANWB?

<grappen over Rusland die data beheert>

S: zullen we anders naar de andere gaan? Het wordt nu een beetje mierenneuken. We hoeven ze niet alle 8 te doen. Wat past er onder autonomie?

C: zelf rijden of niet kunnen kiezen, je route, überhaupt mogen rijden.

NC: een keuze in hoeverre je zelf rijdt misschien, terug naar level 2 als je 3 hebt.

AF: snelheid is wel fijn. C: Die staat ook in relatie met doorstroming en met de privacy . Misschien nog volgafstand of positie op de weg.

C: Is het nog nodig om een linker en rechter strook te hebben. S: Laten we van gemengd verkeer uitgaan, dat is wel interessanter.

AF: we zouden nog wel recalls kunnen doen, dat tie niet meer mag rijden als de fabrikant hem niet meer vertrouwd.

S: Het is al een keuze denk ik, dus we het gaat om ja of nee. Laten we met de eerst beginnen: zelf rijden of computer.

Allen: ja. C: ja, klopt. S: Stel het is spits, A4, zet nu je ZRA aan dan gaat de doorstroming omhoog, moet dat kunnen?

AF: want je kan het dan alleen aan als iedereen mee doet.

NC: maar het is gemengd. Het kan dan nog wel helpen inderdaad. Maar 1 iemand kan het verpesten.

S: dat dus dat het aan moet is discutabel. Maar moet het uit moeten.

N,C, O: ja prima. AF: zou ik raar vinden.

O: bijvoorbeeld als bij wegwerkzaamheden. Bij Antwerpen staat een bord dat je cruise control uit moet.

C: Ik denk dat dat ook moet kunnen. Bij ongelukken moet het dan uit kunnen.

AF: Nu wil je nog alle functionaliteiten altijd aan hebben. Ik wil altijd zelf kunnen kiezen, maar is het over 10 jaar wel anders.

C: maar er moet een voordeel bij zitten om het altijd uit te mogen zetten. Er moet duidelijk een reden voor zijn.

S: Ok, en mogen rijden.

NC: je snijdt jezelf. C: of je vrouw bevalt. Dat moet altijd kunnen.

AF: Misschien bij een recall dat het niet kan. C: misschien wel dat de autofabrikant de zelfrijdende functie uit zet. Omdat het gehackt is of iets dergelijks. NC: maar over het algemeen ja.

S: Route dan?

O: keuzes zijn ja of nee toch?

NC: Als hij aanstaat alleen keuzes, geen dwang. O: Dat je opties krijgt. Je mag niet weten. AF: Maar is het niet later misschien iets anders. Over 10 jaar is het misschien heel anders. NC: Maar dus niet verplichten. Eventueel adviseren.

S: en snelheid?

NC: hetzelfde denk ik. Je mag gewoon te hard rijden.

<anekdote over Tesla en achterin zitten met mensen>

C: Mag je harder rijden dan mogelijk is? AF: Ik ga niet toestaan dat je harder kan als ik verantwoordelijk ben. Dat wil ik niet. NC: Je moet aan de regels houden, anders is de fabrikant niet meer verantwoordelijk.

C: Ik rijdt soms ook iets te hard, omdat je dan mee rijdt. Even harder rijden om iemand in te halen. Mag dat? Anders rijdt je achter je buurman.

<discussie over inhalen>

S: Dus normaal liever niet, maar soms wel.

NC: maar dan is het wel jouw verantwoordelijkheid, jij wil dat.

AF: Misschien mag je m instellen, maar dan alleen de bovenkant. De auto moet het bepalen als jij het hem laat doen. Boetes zijn gewoon voor jou als je 140 rijdt.

C: Of je moet zelf stout willen zijn.

<korte discussie over plaats op de weg>

S: Ik denk dat we deze nu ook hebben. Zijn er nog dingen die ook moeten/

NC: Ja, bij veiligheid. Ik wilde nog zeggen dat ik een gevoel van veiligheid wil. Het is lastig te meten.

S: In NL daalt het aantal moorden en overvallen, maar het gevoel van veiligheid daalt.... Das raar. Kan het gevoel ons iets uitmaken. Is dat van belang?

AF: het heeft wel met acceptatie te maken.

C: Het zijn wel factoren die meespelen. Als iedereen het stom vindt om er naast te rijden lijkt me onhandig.

AF: gevoel van veiligheid geldt voor beide. De bovenstaande punten zijn harde bewijzen, maar de ander is misschien lastiger.

S: Vinden jullie als het gevoel voor veiligheid in het geding is, moet de overheid er dan iets aan doen?

AF: ik denk dat het belangrijk is, maar het gaat ook om bekendheid. Als je vaker ziet dat het goed gaat het beter.

<anekdote over de eerst film waar een trein op het publiek in reed en iedereen de tent uit rende>

NC: je wilt ook niks hebben wat echt heel eng lijkt.

AF: Die halve secondes kunnen best lang zijn.

S: Maar dus het gevoel is ook van belang.

AF: Ja, blijkbaar wel. Media heeft wel hierin een rol. Bij vliegtuigen is dat heel erg duidelijk.

C: een tijdsperiode is ook nodig om het te regelen.

O: geleidelijk is handiger.

Appendix P: Codes from the workshops

Closed coding to see if the workshop is 'a dialogue'

Codes	
Topic is set by participant	"Ok, safety is important for us all, right, let's start there" Non-consumer, S1
Question asked to other participant	"Why aren't there any of your points on accessibility for everyone Non-consumer?"(Car manufacturer, S1) "No points for equality?" (Government, S2)
Discussion with other participant	But, people can give more points on spending time differently, right? Three of our chips are already there. What do you find important?" (Consumer, S1) "Isn't it a task of the government to stimulate the economy? Spending time differently is than one of the aspects which makes this possible." (Car manufacturer, S2) G: "Ok, I don't think that is important". CM: "why not? More efficient people is more economic growth right?" NC: "what would be the downside". G: "well, it's not unimportant, but less than others." S1 "But, people can give more points on spending time differently, right? Three of our chips are already there. What do you find important?" (Consumer, S1) "Isn't it a tast of the government to stimulate the economy? Spending time differenly is than one of the aspects which makes this possible." (Car manufacturer, S2)
Respect	
Unresentful behavior	
Respect for being different	"C: I like spending time differently. NC: Me too, but less than you value it" (Consumer and non-consumer, S1) "I think it's strange that this aspect is not in the spotlight. I just don't want a car which you can trace

	online."
No respect for being different	
Equality in the discussion	
Use of power position	"M: We could give everyone points to divide, but that would be strange as without manufacturers there won't be cars. G: And without me they won't be allowed on the road. [discussion changes subject]" (Manufacturer and Government, S1) "If I pay for the car, I want to get something for my money. Otherwise I'll stay in my current car" (Consumer, S1) "I would like to make regulations, but you have to build it in your vehicles" (Government, S2)
Honest	"If I pay for the car, I want to get something for my money. Otherwise I'll stay in my current car" (Consumer, S1)
Un-honest answer	
Open about their interests	"Traffic flow is of importance, I want to arrive quickly at my work. But, safety is even more important, I have doubts with the safety, as it feels like a black box [….]. Those values are interesting developments, but only after other aspects are covered." (non-consumer, S1) "It is not unimportant, it is that I prefer other points above this one. It's a nice side effect though." (Government, S1) "Well, I like safety, but the other points are not of my interest" (Consumer, S1) "It's important that there are less traffic jams and less accidents. Also the environmental aspect, linked to the traffic flow is of importance. The rest is fine, but of less importance" (Government, S2) "The amount of accidents needs to be a lot less. Safety therefore gets the most points. Some aspects are important for the users, but less for me, but still are of importance for the acceptation. Spending your time differently for example. This is more a marketing aspect" (Car manufacturer, S2)

	"I also find safety important. That is the main reason we are doing this. The environment and traffic flow are also of importance." (Consumer, S2)
Listen to each other	
Not listening to each other	
Help each other in formulating arguments	"Looking this far ahead is difficult, wat would you like the government to do?" (Government, S1) "I see here that security is not valued that much. Perhaps the government would like some chips on that aspect" (Car manufacturer, S2)
Acceptable arguments	
Use of fallacies or discussion tricks	

Open coded statements to see if van de Poels statement can be confirmed in an empirical setting and to see if the workshop was 'constructive'.

Specification of values / Trace more precisely the value judgements	"I would like to have a safe environment, but also that I can estimate how safe it is. I want to know that they have seen me" (Non-consumer, S2, already in step 1) "We should split this up into use of data and autonomy" (Car manufacturer, S2) "We are talking about level three, right? Then I say 10 times less deaths." (Car manufacturer, S2)
End norms hard to relate	"10 times less is fine. Sounds simple. To make all accidents disappear is a lot, that's too complicated" (Non-consumer, S2) "Or for example on the level of how banks are secured nowadays" (car manufacturer, S1)
Relation between values	"This really contradicts with the autonomy of a user. Without an issuance your car won't drive. Or with a tax depth." (Non-consumer, S2) "This aspect is also in relation with traffic flow and pricay" (Car manufacturer, S2)
New idea's arise	Consumer: "I think cars have to be traceable. So, the car manufacturer is responsible to get it back. Or to give me a new one.

|	
	He knows where it is. Government: "So you are not the one to find it, or the police but the government." Car manufacturer: "I will make that that think won't be stolen anymore. "
Becoming to practical	"What can be decreased the most: deaths or serious injuries?" (Non-consumer, S2)
Constructive	"Let's first search common ground. First there more points. And there might be points which no one scored yet, but we now want to score together" (Non-consumer, S1) "In this way we don't work together, we are still dividing points on our own" (Government, S1) "We need to discuss the points, there might be people against some points" (Non-consumer, S2)
Negociating	"
Definitions values	"It depends on the definitions we found what I value" (Car manufacturer, S2) "There are two sides. Freedom and data, or that might be called privacy" (Non-consumer, S2)
Overlapping values	"Certain aspects overlap, which make it complicated to divide points. Safety and spending time differently. Or safety and security." (Consumer, S2) "What I see is that some aspects have a direction. You can formulate them in favor or against. We have no anti-votes here" (Consumer, S1)

Appendix Q: Specifications from the workshop

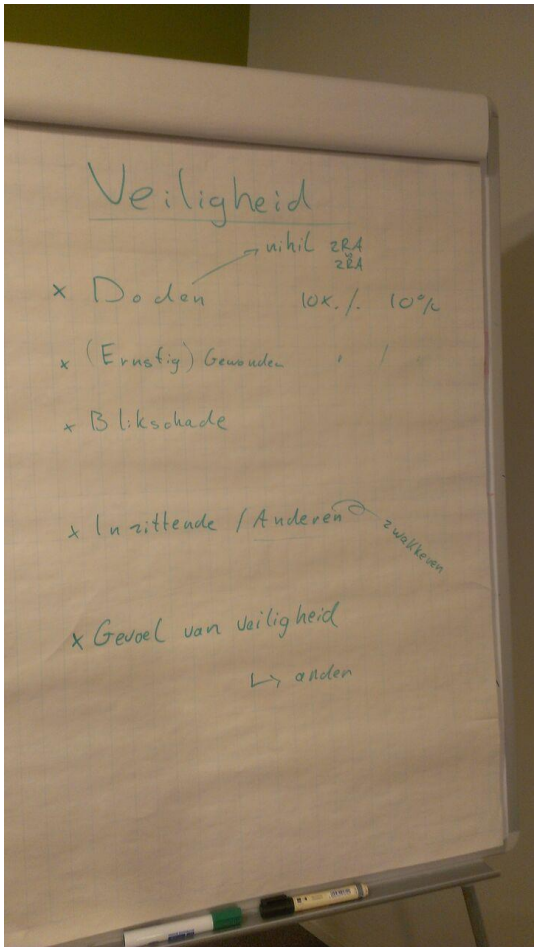## 15.4. Specification workshop 1
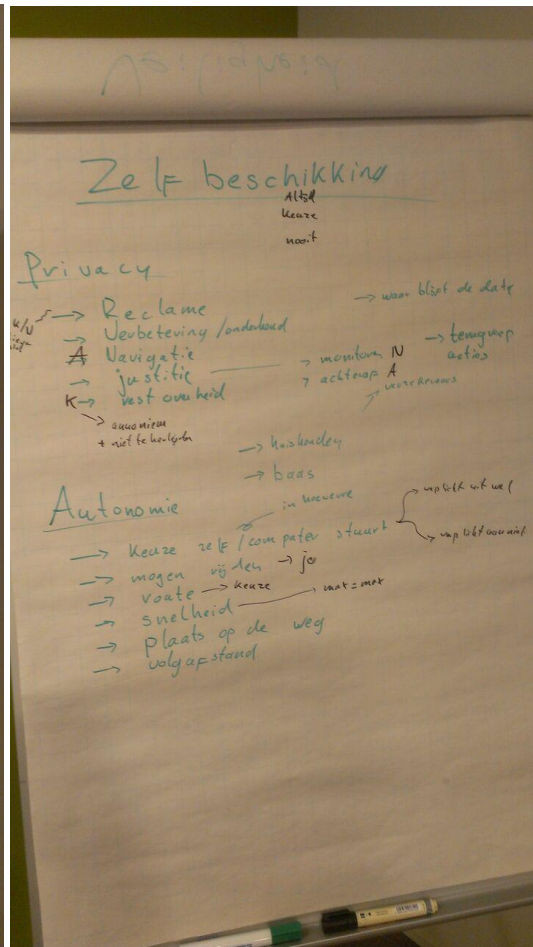
Safety & Security
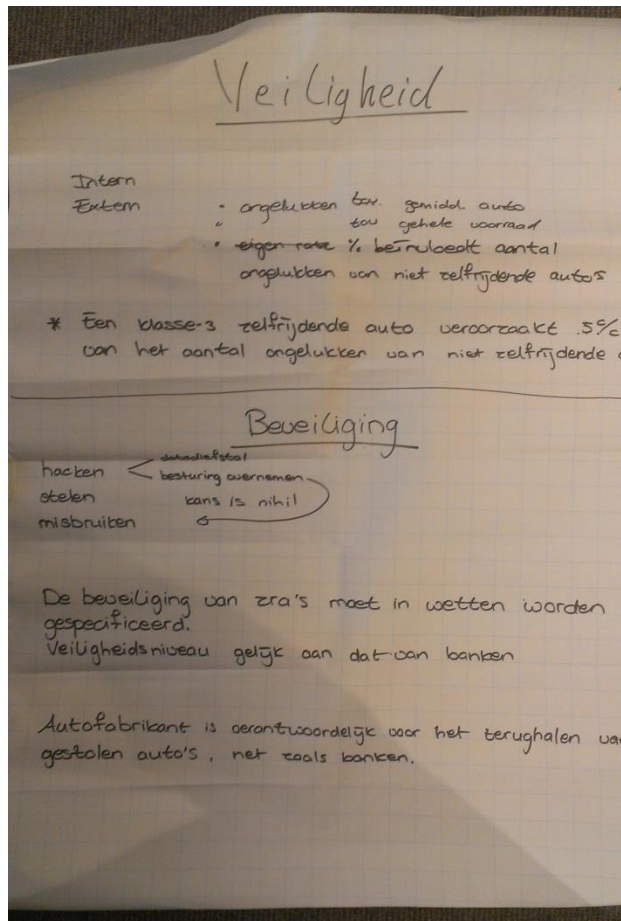
Traffic flow
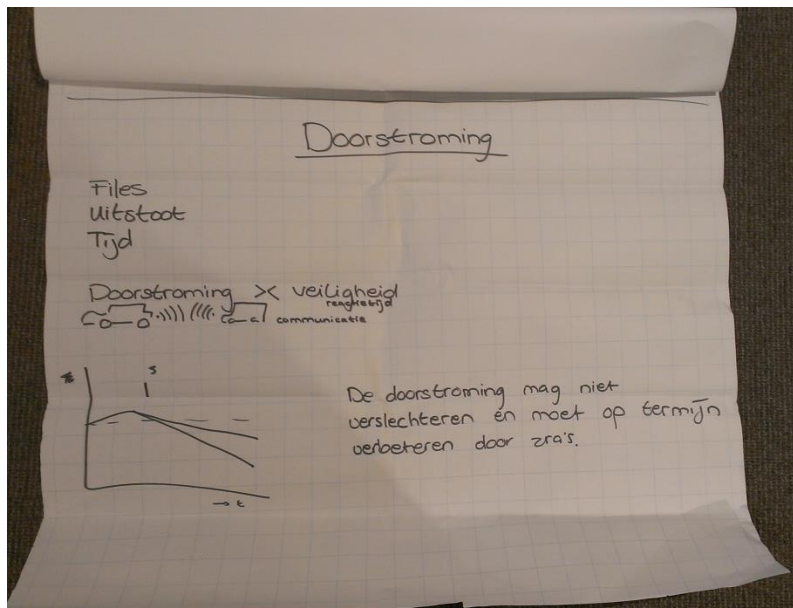
Specification workshop 2

Safety   Self-determination

Appendix R: Integration Essay

The Responsible Future of Automated Vehicles

Introduction

Context

While some discussion exists about *when* we can expect automated vehicles (AVs) to appear on public roads on larger scale, the questions *whether* these vehicles will appear on the market seems to have been answered positively: AVs will be part of our future. Even though it remains unclear in which precise shape or form these AVs will appear, both traditional car manufacturers and newcomers on the automotive market in Silicon Valley are clear about one thing: they are working on prototypes (Anderson *et al.*, 2014: 4), like the Google car and the Tesla model S.

Automated vehicles are expected to be a disruptive innovation with large societal impacts (Manyika, Chui, & Bughin, 2013). The prospects of AVs for the transportation sector, including self-driving cars for consumers and self-driving trucks for commercial transportation, usually contain elements of increased efficiency (less congestion or traffic jams), less emissions, and increased safety on the road. The Ripple-model (Milkais *et al.*, 2015) further specifies these projected advantages, for various degrees of automation ranging from driver assistance to full automation.

Still, there are different types of AVs and developing paths. E.g., it remains unclear whether cars will be connected or autonomous, as well as what kind of business models manufacturers have in mind. The notion that AVs have a positive effect on society is widespread, but might be accompanied with undefined liability, security or safety concerns and *"...without new privacy standards, a default lack of privacy for personal travel may become the norm"* (Fagnant & Kockelman, 2013: 1).

However, in our experience in working on the societal context of disruptive innovations, we cannot help but feel that both the AV as an innovation and their positive prospects should continue to be scrutinized rather than taken for granted. The responsible thing to do would be to continuously reflect on the possible benefits and drawbacks. However, critical reports about the future of AVs are very few in numbers. The Dutch Rathenau Institute has recently published a report titled *"Linking self-driving cars to public goals"* (Timmer & Kool, 2015: 35). This report warns that citizens and interest groups should be involved in the process, as *"... their input is essential for societal embedding of the smart car."*

We realize of course that 'the' AV doesn't exist. As said above, AVs come in different degrees of automation, and market introduction will probably be gradual rather than immediate. Still, we find it important to consider how the responsible introduction of AVs can be smoothened, from a socio-ethical and socio-political perspective. As manufacturers are not always clear about what kind of innovations they are developing (both concerning the product, and the business model behind it), the process of development and circumstances of introduction and embedding are difficult for the public to participate in. As a result, the public has no "kollektive Vorstellungsbasis" or "clear collective image" of the product (Fraedrich & Lenz, 2014). After comparing 10 recent surveys studies Kyriakidis et al. (2015, p.3) conclude that "…people also indicate a non-negligible level of reluctance" for automated vehicles. People might like a car that brings them faster at work, while they are reading a paper, but a car which leads to more congestion and harms privacy is also not unthinkable and probably also less desirable. This makes the extent to which there is a market (consumer) demand for AVs is far from clear.

Even though it is generally acknowledged that policies allowing and facilitating AVs should be designed now (Anderson *et al.*, 2014), and that the future of AVs needs more public discussion (Timmer & Kool, 2014) practical ways or even suggestions of ways to establish political and public discussion are lacking. This places the economic, social, ethical and political landscape around the innovation of AVs in somewhat of a gridlock. We feel this should be remedied in order supply society with a product that is economically feasible, socially acceptable or even desirable, politically and legislatively possible, and of course technologically safe and sound.

o **Paper aim & structure**

In this paper we first analyse the socio-ethical and socio-political dynamics around AVs, thereby discussing the extent to which AVs can be considered a Responsible Innovation (RI). Based on this analysis we subsequently propose a number of recommendations to further help support the development of AVs in a responsible manner. Our main aim is to call for a change in the innovative landscape of AVs, towards a more socially inclusive, transparent and reflexive modus. The remainder of this paper is structured as follows. *Section 2* gives some further background information on the various types of AVs that exist, and their projected societal benefits. It also presents some background on RI. *Section 3* presents our analysis of AVs in the context of RI. We conclude with *Section 4*, on how we envision the responsible future of AVs to take shape.

Background

Different levels of automated vehicles

Over time the car fleet gradually will be become more automated. The Society of Automotive Engineers (SAE international, 2014 defined 6 levels of automation, in which level 0 is a vehicle without automation and level 5 a fully self-driving vehicle. First versions of automated vehicles are already on the road: in new luxury models adaptive cruise control and lane keeping are widely available (level 1 / 2). The most extreme AV innovation is a vehicle where the human is out of the loop, and computers are responsible for the driving (level 5). Most traditional car manufacturers are developing automated vehicles step-by-step, i.e. they first develop and bring to market a level 1 vehicle followed by more advanced versions. However, some non-traditional companies don't believe in such 'linear' innovation: developers like Google aim for what they call a "moonshot" (see e.g. Levy, 2013).They directly aim to develop a car where a human is not a driver, but a passenger.

Anticipated effects

Together with a rise in automation, a rise of benefits is expected. Most mentioned benefits are less accidents, higher traffic flow efficiency and less emissions. Milakis *et al.* (2015) developed the 'Ripple' model which links the levels of SAE to the expected impacts. They expect that level 1 and 2 AVs only influence traffic related aspects such as traffic flow, capacity or the preference for a car. Level 3 (conditional automation, driver can do something else while driving, but has to take over if the car asks for this) can have infrastructural effects, effects on vehicle ownership and some spatial effects. For level 4 and 5 more broader economic or societal effects are expected. Especially the impacts of the last levels can be called a 'system innovation' (Geels *et al.*, 2004) and can radically change not only transportation, but also housing, economy and spatial planning as there is no need for parking spaces and everyone can make use of a car, even without drivers license.

It is expected that AVs will have a positive societal impact. Various sources describe positive possible societal impacts, such as a higher traffic flow (Hoogendoorn et al. 2014), less accidents, a different use of the time and less emissions (Fagnant & Kockelman, 2015; Litman, 2014; Snelder *et al.* 2015). However, specific scientific evidence that automated vehicles will lead to higher capacities, less traffic accidents or less emissions is of course impossible to find without large scale tests. To partly solve this Collingridge-like dilemma, of course there are simulations, studies and analyses done to predict the effects, which all hold assumptions about how software engineers will program the vehicles. Congestion for instance will only resolve if vehicles hold smaller distance to predecessors than now is the case. But it is not unlikely that the first automated vehicles will hold

higher safety distances and therefore lead to more congested cities. Car manufacturers, but also third parties mostly explain the benefits automated vehicles could have, communication about risks or uncertainty almost never takes place.

Responsible innovation

In this paper we analyse AVs in terms of the extent to which they can be considered a 'responsible innovation'. We follow Rene von Schomberg's (2013) definition in the European context of Responsible Research & Innovation (RRI), and operationalize RRI with aspects as defined by Stilgoe *et al.* (2013). Von Schomberg defines RRI as *"a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process* and *[emphasis added] its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."*

Stilgoe *et al.* (2013) follow up on this notion by linking RRI to action-approaches in relation to the process of innovation and its outcomes. Shortly summarized, these actions include (1) the anticipation of effects of the innovation, (2) reflexivity by the actors involved in the innovation process, (3) inclusion of viewpoints by both experts and non-experts, and (4) responsiveness, which relates to establishing a capacity to change the innovation process direction to possibly further accommodate broader viewpoints and reflexive insights, and to prevent negative anticipated effects.

These aspects of RRI can be operationalized in practice in different ways, e.g. in the form of stakeholder engagement workshops, courses on enabling reflexive behaviour of scientists and engineers, public debates about the present and future of certain technologies, policy expert meetings and lobby activities to further steer future policies, etc. (Fisher *et al.*, 2015). Experiences with these approaches have been obtained in other technological areas such as biotechnology (Flipse *et al.*, 2013), nanotechnology (Fisher 2007), and also vaccination programmes and nuclear energy. However, efforts in the field of AVs seem to be much less abundant, even though some key stakeholders advocate for such events to be set up, including Mercedes' research head, Thomas Weber (Hall, 2015) and University of British Colombia's Transportation Infrastructure and Public Space lab director AnnaLisa Meyboom (UBC News, 2015). In the next section, we assess the automated vehicle innovation on the RRI aspects described above.

AVs in the context of (ir)responsible innovation

Besides criteria for responsible innovation, Von Schomberg (2013) also describes four criteria for 'irresponsible' innovation. These include technology push, neglecting fundamental ethical principles, policy pull, and lack of precautionary measures and technology foresight. Below we try to link these indicators to various aspects that can be associated with the current developmental practices of AV innovations.

To start with the technology push aspect, an innovation might be considered a technology push if production and sales, following the development phase, take place without proper consideration of consumer needs and related economic market potential. If there would be a formal demand, of which easily available public evidence is hard to find, it would probably be for safety, efficiency and less emission. As the final form of AVs is unknown and impacts are unproven, an explicit demand of consumers cannot be found. In the meantime, R&D of large car manufacturers, and suppliers of AV technology in e.g. Silicon Valley, is hard at work to produce AV technology. Fact of the matter remains, when car manufacturers at some point launch their innovations without preparing a societal and political landscape that is both willing and able to accommodate AVs, the innovation is likely to fail, in line with Von Schomberg's example of genetically modified crops in the 1990s. More worrisomely, in some interviews we carried out over the past year, with various large car manufacturers, some engineers appear to explicitly think that the market will automatically follow when their innovations are launched. We doubt whether this will be the case without any explicit effort on the socio-political and legislative landscape.

Continuing with the policy pull aspect, Von Schomberg mentions some examples of innovations that are developed based mainly on a demand by policy makers (e.g. airport body scanner, and biometrics in passports). In the field of AV, we could say that governments are eager to reduce traffic congestion and emissions. Explicit demands to have automated vehicles on the road for such reductions is not so explicitly outspoken. But there is political interest in this novel type of transportation, indicating a small degree of policy demand (Schultz van Haegen, 2014; Department of Transport, 2015). Still, the baseline for innovations that have a policy pull character should be subjected to public debate, in line with some experts in the AV field also think as we highlighted above. However, a clear action perspective on setting up such activities is currently not being carried out on a large and possibly influential scale.

In terms of neglecting fundamental ethical principles, AV technology does provide some major conflicts. E.g., there are questions about the extent to which safety and traffic flow can go hand in hand (holding distance to other vehicles) or to what extent ownership of data on driving behavior conflict with drivers' privacy. One

thing is sure: it is unlikely that these issues will be resolved solely by a single technology or policy actor. When actors involved, including manufacturers, consumers, political actors, NGOs concerned about nature or traffic safety, etc., are not jointly discussing these issues before AVs are ready to be introduced, it's unlikely that a fitting social and political system is in place on time. Such discussions could lead to designers explicitly consider ethical aspects relevant to the public (broader than just consumers). The extent to which this is done, currently remains unclear: manufacturers currently seem to not openly engage in large open public discussions about their technology. Of course, intellectual property aspects play a role here, and it is probably not easy to resolve design ownership issues, but some transparency or discussions on a more general level about the value of AVs may be welcomed.

Finishing with the precaution aspect, there currently is no scientific proof that AVs are safe, solve congestion, or have less emissions. Two perspectives can be adopted. (1) We allow AVs on the road because there is no explicit reason for concern, because we cannot prove them to be more dangerous than current cars. (2) We only allow AVs on the road when we have scientific evidence that they are safe (i.e. the precautionary principle). Of course, in terms of safety some precautionary measures are taken. E.g. the Dutch and other countries their vehicle authorities do extensive tests (Department of Transport 2015b; SWOV 2015) before AVs can be piloted publicly. The US is already one step ahead as there are already many pilots tests are done, both publicly (Google 2015c) and in secrecy. However, on other aspects as traffic flow, privacy, ethical dilemmas or cyber security, policies based on precaution are still lacking. What also can happen is that governments compete with each other in a space race for the most tests on their roads, as they believe that this is good for their economy. This competition can lead to lower testing standards. E.g. in America car manufacturers complain about stronger regulations (Thompson 2015). The monthly magazine WIRED explains that due to complicated regulations in the US the "The UK just made itself a fantastic place to test self-driving cars" (Davies 2015, p.1).

Concluding, considering the four aspects of irresponsible innovation defined by Von Schomberg (2013) it seems that the AV innovation shows some signs of 'irresponsibilty'. In the next chapter the four signs of a responsible innovation from Stilgoe et al. (2013) will be discussed, and based on these advises for a more inclusive, anticipatory, reflexive and responsive AV innovation practice are presented.

Conditions for Responsible innovation

The operational definitions of Stilgoe *et al.* (2013) are used below to relate the AV innovation to the concept of RRI. The first aspect, anticipation of the effects of the innovation the innovation might have, implies that many

"what if" questions need to be answered. Not only on technological levels, but also "to encapsulate the social, ethical and political stakes associated with technoscientific advances" (Stilgoe *et al.*, 2013: 1570). This is could e.g. be done with Technology Assessments methods including scenario analysis. The innovators developing the product, so manufacturers in the case of AVs, and in case of guiding policies, the government, should ask themselves these what-if questions. Even though some AV future scenarios are written, some are not critical, or not broad enough: e.g., mobility effects of AVs are researched, some economic effects (loss of jobs) are researched, but scenarios for privacy, safety or social effects are not developed, or at least not explicitly communicated. Striking is that most publicly available assessments are not developed by manufacturers or governments but by (independent) other institutions.

The second aspect Stilgoe *et al.* (2013: 1571) describe the reflective aspect, defined as *"holding a mirror up to one's own activities, commitments and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue may not be universally held."* It is hard to prove that car manufacturers are not doing this, but we observe few publicly noticeable signs that this happens. The few signs which indicate a lack of reflection are e.g. Google, who is in silence about the US Consumer Watchdog's claim to ensure that data of the vehicle is only used to navigate (Tech Times 2015).

The third aspect is inclusion of actors in the innovation process, meaning that "inclusively opening up visions, purposes, questions, and dilemmas to broad, collective deliberation through processes of dialogue, engagement, and debate, inviting and listening to wider perspectives from publics and diverse stakeholders" (Owen et al., 2013, p. 38). A few of these aspects are done, but most are lacking. Almost all car manufacturers communicate through the public testing of driving prototypes or with other forms their visions, such as the Google, Mercedes or Tesla. The public can therefore to some extent see how far manufacturers are now in their innovation pathways. However, not all manufacturers are clear about what their future plans (including the AV product and its adjacent business model) are, with Apple possibly as a leading example, with complete radio silence around its possible automated vehicle program (Harris, 2015).

What generally appears to be missing in the communication of visions of manufacturers who *are* open about their products, are their future business models. These business models can be a critical aspect in the privacy debate, as car manufacturers might sell data or use it for commercial purposes. When the US Consumer Watchdog asked for a provision that information gathered by the vehicle could only be used to navigate the vehicle, Google refused to add this (Tech Times, 2015). After many questions of the Watchdog Google started opening up by giving an overview of their research in monthly reports. This may be considered a positive step

towards transparent innovation, but this still entails a view solely from Google and encompasses one-way communication, possibly more a PR statement, then communicating about risks or real ethical, legal or social dilemmas.

This communication leads to a public debate, however a framed one. What currently happens, due to the good working marketing departments of car manufacturers, is that only positive points are highlighted but they do not elaborate upon the risks. Real inclusion as required for RRI entails two-way communication. In such a constructive dialogue, publics and other external actors themselves should be able to ask questions and to bring up dilemmas that need to be remedied. Google made a small first step and could possibly open up more, but other manufacturers seem to have an even longer way to go. By including the public in the innovation process, the societal robustness can more easily be ensured.

The last point Stilgoe *et al.* (2013: 1572) mention is responsiveness, meaning that *"[r]esponsible innovation requires a capacity to change shape or direction in response to stakeholder and public values and changing circumstances"*. So, after inviting the public, or interest groups to comment on the design, these comments could actively lead to updated designs. Interaction through workshops or by consultation events could be a marketing instrument, but also a way to attune designs more to societal demands. Ultimately, this might even lead to a more optimistic public attitude towards AVs, even though there is no consensus on, or evidence that such activities lead to a more receptive market.

Summarizing these four aspects of RRI, in all four aspects we find that the large car manufacturers are not taking full advantage of the possibilities to make their processes more in line with RRI criteria. Most communicate about visions and prototypes but lack to explain more (business models, dilemmas, etc., or include external public viewpoints in their design process. Also anticipating on the broader effects of their technologies are possibly not explicitly and publicly researched, or at least not communicated about. Governments are doing more anticipatory work on the future of AVs, however in their policymaking process and the process of formulating laws, other stakeholders currently only seem to play a minor role.

The responsible future of the car industry

Anticipating possible effects

Responsibly developing an AV has not only technical aspects. Also social, economic and ethical aspects should be taken into account. Considering that technological artefacts (as outcomes of technological development) co-shape our world, and as researchers develop such artefacts, they can (and arguably have the obligation to)

consider connections between context of design and context of use (Mitcham 1994; Verbeek 2006; Swierstra & Jelsma 2006, Flipse *et al.*, 2013). For AVs not only mobility effects should be researched, but also more wide effects as safety, privacy or changes in the social system should be a researched, communicated and discussed with the public. Aspects that these external actors could potentially contribute to, include e.g. the Trolley-problem (hitting a tree or a child, see Jaipuria, 2015). According to the precautionary principle these researches are also needed to allow cars on the road as now there is no scientific proof that automated vehicles will not harm the environment or society.

Transparency

Transparency is one of the points where the AV innovation can become more in line with responsible innovation practices. Some car manufacturers already made great steps in showing what they are doing and planning to do, while others neither confirm nor deny that they are working on AV's (Apple see Harris, 2015). It must be admitted that the innovation landscape is highly competitive, but still more transparent communication is possible without harming business.

Most car manufacturers communicate about at which point in development they are now, and show visions of their future. However, some important aspects remain unclear, which makes it hard for governments, interest parties or citizens to reflect on the manufacturer's activities. Google for instance opens up by showing their models to the world, but does not communicate about their future business model. This business model could involve privacy sensitive aspects like data mining or selling locations of the users. Besides withholding this information the communication is also biased. Many video's, interviews or visions only explain potential benefits, but lack explaining potential downsides. Google made a start by showing their dilemmas and crashes in a monthly report, where other manufacturers don't shown insights in their tests. However, some critics might argue that the Google report is mostly a PR medium than a critical, transparent and reflective medium where potential downsides are also discussed.

If car manufacturers are not transparent, constructive dialogue between the public, government and manufacturers remains difficult. This could even lead to socially less or undesired products, or in the worst case to non-acceptance. Transparency could be improved by not only showing what you are doing now, but also what your plans are, not only technical, but also business model wise. This could also be multiple views, on which the public can comment. Besides this the testing phase is of importance for transparency, what goes well, but also what goes not well should be reported, not only by Google (as happens now), but also by other manufacturers.

Furthermore, not only the technical and business side of the project should be reported upon, but also possible impacts on social or economical factors should be explained. Not only positive, but also negative.

Socially inclusive development

Inclusion implies a certain degree of openness towards viewpoints of actors currently not involved in the development of the AV industry. This is different from our explained need for transparency by the automotive industry about AV technology, in the sense that inclusion doesn't only imply showing what external actors could *have* influence on, it also implies that these external actors *can* actually influence these developments. One of the points of such inclusion is that it may lead to more critical (and thereby potentially constructive) input towards AV innovations. I.e., more critical than technical effects researched by scientists and engineers, as to also include broader economic, societal, social and ethical contexts. We foresee two prominent kinds of inclusion: in the AV technology development itself, and for the development of the legislative landscape.

The development of AV technology itself can potentially also benefit from inclusion of a broader pallet of actors than potential consumers for marketing purposes. We acknowledge that the intellectual property landscape might be difficult around the development of AV technology, but sensitive technical information is not the level on which we advocate for inclusion. Non-technical actors such as (most) consumers still can provide useful input when it comes to the aspects that still need to be organized, including ownership of drive details and routes. These and other aspects can also help in the assessment of societal desirability of AVs. This does require AV technology developers to open up and acknowledge that external actors can have complementary information, in addition to what their market researchers and engineers have themselves.

The development of a legislative landscape that functionally and safely supports AV technology in our current infrastructure, requires well-informed policy making. This includes also actors outside the realm of car and car component manufacturers with lobby activities on national and international levels. Interest groups including car drivers associations, but also sensitive traffic users such as children and senior citizens could have a say at least in designing such policies. Considering the limited amount of public consultation that is currently explicitly visible on national and international levels, we propose that much can be gained here. We therefore call on all actors affected by AV technology (including users, non-users, interest groups, governmental organizations and manufacturers) to contribute to such policy making when the possibility emerges. Simultaneously, we call on governmental organizations to open up the policy room and to allow for well-informed and inclusive, (participatory) policy making.

Concluding remarks

Future of the car industry

This paper argues for a more responsible future of the automated car industry. Automated vehicles will be part of our society and will probably have positive social contribution. Still the AVs can be developed to technical artefacts which are even more tuned to societal demands. To do so this paper has the following encouragements: (1) a call for scientists to research not only mobility effects of automated vehicle, but also more widespread effects such as privacy, economic and the feeling of safety . (2) A call for politics to start making policies for automated vehicles, together with citizens, interest groups and manufacturers. (3) A call for manufacturers to be more transparent about their plans and business models and opinions of citizens and inters groups in their design.

We highlight that these recommendations take the hypothesis as a starting point that RRI could lead to innovations that can be considered more 'socially robust', in the sense that these may be more readily adopted by society. However, concrete evidence of this happening for disruptive innovations is currently still lacking

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Nederlandse samenvatting

Zelfrijdende auto's gaan binnenkort deel uit maken van onze samenleving. De eerste auto's rollen nu de fabriek uit en meer geavanceerde vormen worden op dit moment ontworpen door bijna alle grote autofabrikanten en enkele nieuwkomers. In dit onderzoek worden vroege vormen van automatische auto's onderzocht: level 1, 2 en 3 (SAE). In level 1 houdt de auto automatisch afstand tot een voorganger (ACC). Bij level 2 blijft hij daarnaast ook uit zichzelf binnen de belijning. Level 3 maakt het mogelijk dat de bestuurder een krantje kan lezen tijdens het rijden. Echter moet hij de auto wel kunnen overnemen als dat wordt aangegeven door de auto.

Deze zelfrijdende auto's kunnen de samenleving veranderen. Ze kunnen zorgen voor minder file, minder uitstoot, maar kunnen bijvoorbeeld ook de privacy van de gebruiker en het gevoel van veiligheid bij andere weggebruikers beïnvloeden.

Dit onderzoek bestaat uit twee delen: deel één gaat over wat de invloed van vroege vormen van zelfrijdende auto's op de mobiliteit in Nederland zijn (deel A) . Het tweede deel onderzoekt wat verschillende groepen actoren belangrijk vinden, en of deze samen input kunnen geven voor een ontwerp voor toekomstige zelfrijdende auto's (deel B).

Een simpel model om snel inzicht te krijgen in de effecten van zelfrijdende auto's
In het deel voor transport (deel A) wordt onderzocht hoeveel file er nog staat als er vroege vormen van zelfrijdende auto's zijn. De overheid wil dit graag weten om beleid op te baseren voor de komende jaren. Het probleem is alleen dat de huidige modellen nog niet goed de effecten van zelfrijdende auto's simuleren. Deze modellen hebben niet de mogelijkheid om zelfrijdende auto's als losse voertuigcategorie te simuleren, wat wel nodig is om alle effecten goed te kunnen bepalen.

Om dit wel te kunnen doen is een nieuw model gebouwd wat de effecten van zelfrijdende auto's op de mobiliteit in Nederland onderzoekt tot 2050. Het model is sterk versimpeld en vooral bedoeld als verkenning. De toegevoegde waarde van het model is dat snel verschillende scenario's en alternatieven kunnen worden doorgerekend.

In het gemaakte model verschillen zelfrijdende auto's van normale auto's op 3 aspecten: ze nemen minder ruimte in op de weg (of eventueel meer, bijvoorbeeld vlak na introductie), de bestuurder kan zijn tijd nuttig besteden en hij rijdt zuiniger. Door deze voordelen wordt de auto aantrekkelijker. Het model laat zien dat hierdoor meer mensen de auto's nemen. Deze extra auto's doen de capaciteitswinst deels of helemaal teniet en leiden tot extra files en langere reistijden. Zelfrijdende auto's die niet communiceren (autonome auto's) zullen hierdoor tot meer files leiden. Coöperatieve auto's, die naast naar de weg kijken ook communiceren met anderen, leiden tot evenveel file als in een situatie zonder zelfrijdende auto's. De overheid zal tot de invoering van zelfrijdende auto's van level 4 en 5 andere maatregelen moeten zoeken om de verwachte files tegen te gaan.

Het model kan verbeterd worden door ook ruimtelijke effecten mee te nemen. Ook lijkt het model gevoeliger te zijn dan andere modellen. Een mooie toevoeging zou een CO_2-module zijn die de emissies van de extra autoverplaatsingen in kaart brengt.

Een dialoog om zelfrijdende auto's maatschappelijk verantwoorder te maken

Een groot deel van het ontwikkelen van zelfrijdende auto's gebeurt in stilte achter de gesloten deuren van de autofabrikanten. Af en toe wordt een tipje van de sluier opgelicht via de media, maar meepraten mag de burger niet. Terwijl de zelfrijdende auto een ontwikkeling is die veel invloed kan hebben op de leefomgeving. Het risico is dat belangrijke waarden van het publiek niet worden meegenomen.

De weinig transparante manier van communiceren, de tendens om vooral de voordelen te belichten en het niet betrekken van burgers in de innovatie maken dat de zelfrijdende auto geen "maatschappelijk verantwoorde innovatie" genoemd kan worden. Om dit te verbeteren is het doel van dit onderzoek om een dialoog tussen de ontwikkelaars, de overheid en burgers op te zetten. Het doel van deze dialoog moet niet zijn om mensen te overtuigen zelfrijdende auto's te kopen, maar om het ontwerp van de zelfrijdende auto zo aan te passen dat het zoveel mogelijk maatschappelijke voordelen met zich mee brengt.

Niet alleen dialoog met de consument, maar ook met andere weggebruikers is nodig. Als men een iPad koopt, beïnvloedt dat vooral de koper, maar een zelfrijdende auto beïnvloedt ook de reistijd, veiligheid en misschien zelfs de privacy van andere weggebruikers. Daarom is in dit onderzoek geprobeerd een constructieve dialoog op te zetten tussen de overheid, autofabrikanten, consumenten en niet-consumenten. Zo'n soort dialoog is lastig, aangezien het beeld van zelfrijdende auto's nog niet duidelijk is. "Wat vindt u van zelfrijdende auto's?" lijkt een relevante vraag, maar als nog niet duidelijk is hoe een zelfrijdende auto er uit gaat zien wordt het lastig beantwoorden. Beter is om te vragen "hoe ziet uw ideale zelfrijdende auto eruit?".

Met dit type vraagstellingen is in dit onderzoek gewerkt. Er zijn vier verschillende vormen onderzoek gedaan: interviews, een literatuur onderzoek, een enquête en workshops. Uit de interviews en literatuur zijn 8 waarden naar voren gekomen. In de enquête, met 144 ondervraagden van de verschillende groepen, aangegeven hoe belangrijk de waarden zijn in verhouding tot elkaar. In de workshop hebben studenten de rollen van de verschillende groepen gespeeld en is er geprobeerd om een gezamenlijk 'waardenprofiel' te creëren.

De waardenprofielen laten zien dat er overeenkomsten zijn tussen de onderzochte groepen, maar zeker ook verschillen. De overheid en andere weggebruikers vinden *doorstroming* belangrijk, waar de producenten meer waarde hechten aan *tijd anders gebruiken* en *zelfbeschikking* van de bestuurder. De overheid en andere weggebruikers hebben voorkeur voor het coöperatieve ontwikkelingspad waarbij de voertuigen ook communiceren. De fabrikanten hebben echter een voorkeur voor het autonome ontwikkelingspad. De consumenten hebben geen uitgesproken voorkeur.

Het gevaar wat hieruit naar voren komt is dat de waarden van de makers van zelfrijdende auto's, verschillen met die van andere groepen. Hierdoor kan het dus zo zijn dat er een auto met minder maatschappelijke voordelen of zelfs met nadelen op de markt komt. Als autofabrikanten zelf een dialoog aan gaan met het publiek kan dit voorkomen worden. De methode biedt ook voordelen voor de fabrikanten: nieuwe ideeën ontstaan (wat gebeurde in de workshops), een product wat beter aansluit op de markt wordt ontwikkeld en er worden inzichten uit verschillende hoeken meegenomen.

Social desirability and mobility impacts of early forms of automated vehicles

This work is the master thesis of Steven Puylaert for two degrees at the TU Delft. This thesis consists of two parts, both assessing different development paths of automated vehicles. The first part, part A, is for the master Transportation & Planning at Civil Engineering. This part elaborates upon the mobility effects for early forms of automated vehicles (level 1, 2 and 3 of SAE). For an autonomous and a cooperative development path simulations are performed in the SD-model. This model is developed for this thesis and is based on System Dynamics.

The second part, part B, contains the work for the master Science Communication. Here the social desirability of the different development paths is assessed. At this stage in the development of automated cars, the public is not, or not enough involved in the automated vehicle innovation. Therefore a method is developed where the government, manufacturers, future consumers, and other road users can have a dialogue on automated vehicles. This method consists of interviews, a questionnaire and workshops. The method is tested on small scale.

A summary in English can be read on one of the first pages. On the last pages a summary in Dutch can be read.

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