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What insight can a microsimulation traffic model provide with respect to the impact of autonomous vehicles on urban mobility in the future?

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Summary
Mobility is changing rapidly these days. New technologies happen in quick succession and have become more and more important. Conventional solutions are traffic management and adjustments in the mobility policy. Parallel to this a new trend has developed: (completely) automated vehicles (AVs). It is expected that this will change the streetscene in the decades to come. The autonomous vehicle has got the potential to keep the city of the future accessible, safe and livable. It is important to further inquire into the feasability of autonomous vehicles in order to quantify this.

Most researches into self-driving vehicles have been executed from the idea that mobility in the future will change by using new technologies. Very often the general conclusion of these researches is the fact that in that case a special infrastructure should be necessary in order to use the potential of automated vehicles. However, policymakers are nowadays of the opinion that the road network should not be expanded any further. In this research a radically different and new approach is followed. Attention is focused on the positive consequences of the self-driving vehicle on the mobility in the city of the future. The purpose of this research is to quantify these positive features. The emphasis is on the urban environment.

On the basis of interviews and literature research with respect to automated vehicles it is possible to come up with the most important effects and developments. Subsequently, several experts within the field of mobility have been interviewed about the future urban mobility. In view of these results four future scenarios have been described for the city of the future and the importance of self-driving vehicles within these scenarios. The scenarios are the following: 1) modernist city, 2) pleasurable city, 3) intelligent city and 4) comfortable city. For each scenario a different set of features and behaviour concerning self-driving vehicles is necessary. Consequently, the features of these scenarios have been translated into revalued parameters of vehicles in the microsimulation model. By analysing these, a lot of empirical data have been collected. Using microsimulation has provide more insights into the mobility of the city of the future. Two criteria that play an important part concerning these insights are traffic flow and road network capacity.

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1. Project background

1.1 Motivation

Nowadays a big transition in mobility should take place in order to achieve more livable cities. The technology of self-driving vehicles could have the possibility to help this transition, which has been widely accepted. 'Drive Sweden' has produced an animation (Figure 2) showing all the benefits of Automated Vehicles (AVs). This was the starting point of this research. The infrastructure in a city cannot expand radically anymore, because of infrastructural facilities. Urbanisation is a common phenomenon, which results in overcrowded cities. Making more space for the inhabitants is almost impossible. Nevertheless, everyone would like a nice a livable environment, together with a quiet and picturesque location without any vehicles. So, on the one hand, urbanisation with more and more traffic has increased and on the other hand the desire for a quiet, peaceful environment has developed. Furthermore, there is the problem of an increase of traffic accidents. A solution to this situation might be found in changing vehicles into automated ones. This could result in a transformation of the mobility with, as a consequence, more sustainable and livable surroundings. Automated vehicles could solve problems if they are deployed in the right way.

This research is meant to contribute to the use and development of automated vehicles within the city. Not only will quantitative knowledge be added to a scientific topic, but also the results will show that quantification of mobility concerning automated vehicles in the urban environment is possible. In this research four scenarios will be translated into parameters which can be valued in order to simulate mobility by using the microsimulation traffic model S-Paramics. Finally, this research should show the advantages of the microsimulation traffic model. Using the model should provide some insights into the behavioural aspects of the urban mobility and contribute to the deployment of automated vehicles in the cities. This research should lead to the achievement of inspiring the policymakers and other interested parties with respect to sustainable mobility by using this upcoming technology of autonomous driving. It is important for to be aware of the unstoppable transition in mobility which can soon be expected and to prepare the urban environment for autonomous driving. It is also essential to use this upcoming technology in such a way that this can lead to a more sustainable mobility and not to oppose this. The microsimulation traffic model can help to achieve this.

1.2 Problem field

1.2.1 Traffic and infrastructural problems

Mobility is changing rapidly as new technologies have recently become more and more accessible and available. In the Netherlands ten million commuter trips were made every in 2013/2014. The average daily travel distance was 32 km and 73% of that distance was covered by cars (Centraal Bureau voor de Statistiek, 2016). Dutch citizens spend a lot of time in their cars. Mobility is very important to Dutch society, but participating in traffic is not without risks. In 2015, 621 people died as a result of traffic accidents and in 2014, 20.700 were seriously injured (Centraal Bureau voor de Statistiek, 2016). This alarming number of casualties shows the importance of the need for new technologies in order to improve traffic safety.

Beside the amount of accidents, there is a second problem to address. This is the time loss caused by traffic congestion. Recent years show an increase in the level of traffic congestion. Compared to 2014 the number of vehicle hours in 2015 rose by 22% while the total traffic in that period only rose by 2%. If a longer period of time, i.e. between 2005 and 2015, is considered, an increased by 12% of the total traffic (RWS & KIM 2016) is noticeable. It is expected that the travel time which is lost because of e.g. traffic jams, will continue to increase in the future. This is shown in the predictions of the KIM 2016.

Researchers investigated that an average traffic growth of 1,5% a year can be expected for the period between 2015 and 2021. The time lost in traffic will increase by 38% according to 2015 (KIM 2016). Bluntly expanding the road network has proven to be unsatisfactory in the past. Additional mobility management measures are needed to reduce the increasing of traffic flows (e.g. road pricing, road user charges, investments in other modalities etc.). Some of these measures however are complex and do not guarantee success in limiting mobility, traffic growth and congestion. Especially in cities figure 1 show the increase of congestions per city in the Netherlands in recent years.

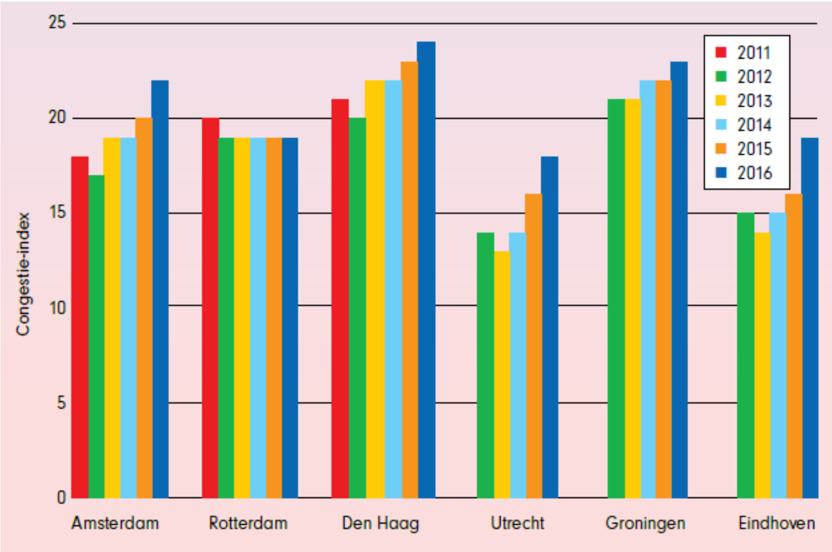


Figure 1 – Increase of congestions per Dutch city in recent years (source TomTom).

Current technologies, such as road expansion, added bus services and smart traffic systems, have reached their maximum capacity (Spieser et al., 2017). Therefore, other transitions in mobility and new technologies are necessary to keep the mobility in the city on the same level or even improve it. As a result of the current urbanisation trends, cities will face rather big problems to keep the adequate service level and infrastructure, which are necessary for the transportation demands of the growing amount of inhabitants. Autonomous driving seems to be a promising technology to keep the city attractive in the future.

1.2.3 *Automated vehicles, the solution?*

Technologies that help us solve these problems are therefore very much in demand, not only because they can probably solve these problems, but also because they contribute to the traveller's comfort (Milakis et al., 2015). One of the most widely accepted technologies that will transform the mobility system in the coming years are automated vehicles (Gruel and Stanford 2016). The automotive industry would like to respond to social problems related to traffic and transport to reduce congestion, environmental pressure and increase safety (Elzen et al., 2002b). Of course the automotive industry also aims at the market opportunities resulting from the increase of the driver's comfort. One of the first ideas and predictions with respect to cars that could drive by themselves came from the General Motors' highly influential Futurama exhibition in New York in 1939. They argued that from 1960 onwards it would be possible for cars to correct human faults while driving (Townsend, 2014). At this moment it seems that the technology of automated driving has come true. The automotive industry has invested in automated vehicles, policymakers allowed many pilot programmes and big ICT companies put a lot of effort into this technology. Automated vehicles have the potential to increase the road capacity, contribute to safer mobility systems, provide mobility to elderly and disabled people, save fuel and lower greenhouse gas emissions. Besides this , there are a lot more advantages, when shared rides and vehicles lead the automotive sector to becoming an on-demand service (Fagnant and Kockelman 2015).

Figure 2 – The Drive Me project visualised possible implications of automated vehicles (source: video ´Drive Sweden - Our Vision – A new approach to mobility).

However, there are also some uncertain elements of the possible benefits of autonomous vehicles for the urban environment. Several scientist are skeptical, especially about the transition phase towards 100% autonomous driving. Some researchers conducted different scenarios that showed that the implementation of automated vehicles does not lead to the results car manufacturers promise (Milakis et al., 2017; CPB 2015). Aspects such as peak-hour travel volumes and weekday travel volumes will increase, according to most of the scenarios provided by a case study by Lisbon as a result of a research by the international transport forum (2015).

1.3 Scenario approach

For the first time scenarios with automated vehicles have been simulated in the microsimulation traffic model S-Paramics. In order to add new insights to the developing knowledge of the future mobility with autonomous vehicles this, research is also aims at quantifying the future mobility with autonomous vehicles with a focus on the urban environment. Furthermore, this study aims at giving an insight into the parameters that characterise traffic flow and their valuation to make simulations of autonomous vehicles in microsimulation traffic models possible. This has led to insights in the development of traffic models which include autonomous vehicles. State-of-the-art inclusion of autonomous vehicle behaviour within simulated urban environments is of importance. This will give policymakers the opportunity to make better decisions to keep the cities of the future livable and accessible.

1.3.1 Why scenarios?

An important tool for future studies is the scenario. Scenarios try to take all possible future events into account (Burt et all., 2006; Chermack et all., 2001; Mietzner & Reger, 2005). Uncertainties of what might happen can be captured by scenario planning, as was stated by Wilkinson. He is of the opinion that this helps scenarists to recognise disrupting events early on, so that they are well prepared and can come up with appropriate responses in case these events really happen (Wilkinson, 1995). Schwartz (1991) calls this phenomenon future memory. With respect to urban design, scenario building is an often used tool for researchers and policymakers in order to consider different transition paths (KIM 2017). One of the first steps during this research will be conducting scenarios. The exact situation of mobility and infrastructure in a future urban environment is unknown. Therefore only the present situation and perspective with respect to the need for mobility will be take into account.

1.3.2 Why microsimulation?

There are several reasons to use microsimulation.

First of all quite a few studies provide scenario analyses about automated vehicles in all kinds of situations: on the motorway, in urban areas, in the near future, in the long run and with different levels of automation. Another interesting view on automated vehicles is provided by Milakis, Van Arem and Van Wee (2016), which shows the ripple scheme effect caused by automated vehicles. More information about this ripple scheme is provided in paragraph 2.1. But all these studies do not aim at quantifying the scenarios. This research on the other hand, does have this purpose. With the microsimulation traffic model, S-Paramics, quantifying the participation of automated vehicles in the cities. is very well possible.

A second reason is explained by Rasouli and Timmermans (2013). In order to meet the needs of adequately making policy decisions, researchers should shift their focus from aggregate to microscopic models. As an increasing complexity of the decision making process and increasing personalisation of decisions and lifestyles, has become inadequate. More integral microscopic models of choice behaviour, allow for more integral policy performance assessments. In paragraph 4.1 the state of the art of microsimulation in combination with automated vehicles and some advantages and disadvantages are explained more in detail.

The scenarios of mobility in the future city have formed the basis for the microsimulation traffic model (MSTM) S-Paramics. Later on**,** the features of automated vehicles have been added to the model in order to reach the desired scenarios. In the end this traffic model has been tested in order to check, whether the possibilities of automated vehicles come up to the expectations. Especially the choice behaviour of the vehicles will be tested in these features. The model with social economic data and infrastructure of Eindhoven is used, because Sweco has got a lot of data about the mobility and road network in this city.

1.4 Process design

Several research questions have been developed to see if microsimulation has really got possibilities to simulate the behaviour of the automated vehicles and therefore can provide more insight into the future mobility than other approaches do.

1.4.1 research questions

This research is mostly exploratory as have been explained in the chapter above. That is why the following main research question and subquestions have been formulated:

Main question

What insight can a microsimulation traffic model provide with respect to the impact of autonomous vehicles on urban mobility in the future?

Subquestion 1
What is the state of the art of microsimulation and modelling automated vehicles in cities?

To provide a solid foundation to answer the main question, this subquestions should be answered with the help of literature studies and interviews.

Subquestion 2
What are the advantages and disadvantages of using microsimulation regarding modelling automated vehicles in cities?

The second subquestion shows the advantages and disadvantages of the microsimulation traffic model in order to empirically determine and quantify the effect of autonomous vehicles in the mobility of the future cities. The difficulty to come from qualitative to a quantitative answers can be tackled with the use of microsimulation. With the literature research the advantages and disadvantages of this use have been explained.

Subquestion 3
What scenarios cover most of the opportunities that are relevant concerning the future urban mobility?

While providing the answers of subquestion two, question 3 needs to be take into account, because the relevant scenarios have to provide the behavioural changes of the vehicles to model with microsimulation. In-depth interviews with experts and literature researches have been taken into account when developing the scenarios.

Subquestion 4
In what way can scenarios be translated into the microsimulation traffic model?

Subsequently, the scenarios with their characteristics have to be translated into the microsimulation traffic model. This have been one of the most challenging questions to answer. With the help of MSTM experts and testing with the model the parameters could be revalued with respect to the features of the scenarios. This was the most important step for the translation.

Subquestion 5
What can be concluded with respect to the results of the micro simulation traffic model especially about road network capacity and traffic flow changes?

After having answered the first four questions, the traffic model can be run. The model provide data about Vehicle Hours and Vehicle Loss Hours this can interpreted into road network capacity and traffic flow changes. As a result this leads to some empiric data and quantified answers. Hopefully this provide some insights in the use of microsimulation and decision making for the urban future mobility with automated vehicles.

1.4.2 Methodology

During this research several methods have been used to come to an effective result. The steps that have been taken are shown in figure 3. First of all, data about the subject have been obtained by studying literature and later on also by interviewing experts. This has resulted in the main question and the sub questions. By means of brainstorm sessions this information has been used for the identification of the parameters of the MSTM and for developing the scenarios. The qualitative scenarios and the quantitative parameters have been combined in the next step, which is revaluing the parameter based on the scenario features. This results into two processes: modelling the MSTM and setting up hypotheses. The analyses of the model result in empiric data i.e. Vehicle Hours (VH) and Vehicle Loss Hours (VLH) . These have been used for two processes, i.e. testing the hypotheses and interpreting these with respect to two criteria. The latter has also been used for testing hypotheses. Also this interpretation into traffic flow and road network capacity has been used for testing hypotheses. The last step of the research is answering the main question by looking into the tested hypotheses if the empiric results and therefore the MSTM could give insights in mobility of the future city with AVs. In the rest of this chapter some of the processes are explained a bit more.

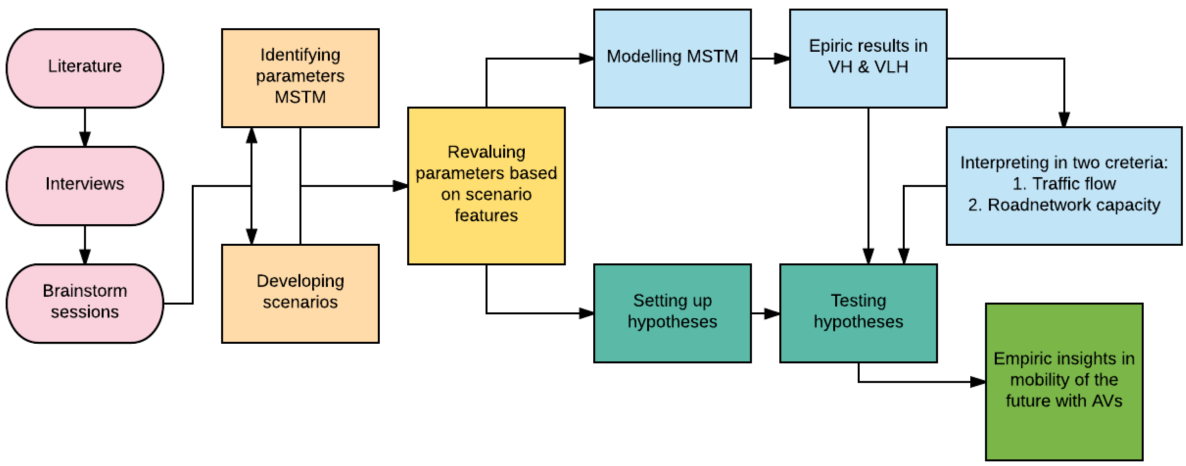


Figure 3 – Process design in presented in a scheme.

1.4.2.1 Input for research

1.4.2.1.1 Interviews

The interviews are semi-structured. Key-people have been carefully selected. Those who have the most experience with respect to particular knowledge about autonomous mobility and vehicles, urban planning, urban mobility, infrastructure and traffic models will be asked to participate (table 1). First of all, to collect as much information as possible and later on to value and choose the parameters which are used in the microsimulation traffic model. Results of the interviews are summarised in paragraph 3.1.

The following table shows the experts who have been interviewed and/or have been involved brainstorm sessions.

Experts:	**Organisation, company & agency**	**Expertise**
Lot van Giesen	Gemeente Eindhoven	Future mobility and infrastructure of the city of Eindhoven
Rudy Stevens	Gemeente Eindhoven & Sweco	Future mobility and infrastructure of the city of Eindhoven
Martijn Drosten	Sweco	Future mobility and infrastructure
Peter Pelzer	University of Utrecht (urban futures studio)	Future mobility and infrastructure
Auke Hoekstra	University of Eindhoven	Automated vehicles and traffic modeling
Carlo van der Weijer	University of Eindhoven	Automated vehicles
Danielle Snellen	PBL	Future mobility and infrastructure and automated vehicles
Hans Nijland	PBL	Future mobility and infrastructure and automated vehicles
Jeroen de Wit	Sweco	Traffic modelling

Jeroen Quee	Sweco	Future mobility and infrastructure
Ron de Bruijn	Sweco	Automated vehicles
Tom Brijs	Hasselt University; Institute for mobility	Automated vehicles
Maaike Snelder	TNO	Future mobility and infrastructure and automated vehicles
Lauren Isaac	EasyMile	Future mobility and infrastructure and automated vehicles

Table 1: Overview of interviews showing the name of the expert, the organisation and field of expertise.

1.4.2.1.2 Brainstorm sessions

Next to the interviews, brainstorm sessions with experts have been organised in order to conduct scenarios. These have been structured as follows: group discussions, which started with an open question, have been held in order to trigger ideas for scenarios, mobility features and automated vehicle parameters. Secondly, all the ideas have been clustered. The last step is rating the clusters on a scale and valuing the useful parameters. These sessions have provided the scenarios for the traffic model. The interviews and brainstorm sessions that have been held mainly with the same people as listed above.

1.4.2.2 Phases of empirical approach of the scenarios approaches

Phase 1a: developing scenarios of the future mobility in the city

With the help of interviews and literature research different scenarios are have been developed. Examples of mobility features in the future urban areas are: traffic flow and velocity, more living space, optimal occupation, optimal achievability within mobility and experience. These scenarios will form an optimised picture of the mobility in the city with automated vehicles.

Phase 1b: identifying parameters of the MSTM

The features of the scenarios have to be translated into the MSTM. That is why it is important to identify the parameters of the model. With this identification the qualitative scenarios can be translated into the quantitative parameters.

Phase 2: revaluing parameters based on the features of the scenarios

During the revaluation of the parameters of the MSTM based on the features of the scenarios, the components of the automated vehicles in the model have been valued. In this phase brainstorm session with experts on the field of microsimulations contribute to the revaluation.

Phase 3: modelling the MSTM and setting up hypotheses

In this phase the MSTM has been modelled to gather empiric data and some hypotheses have been conducted. In the discussion of this research these hypotheses are presented. Prior to the empiric approach the scientific debate, whether or not to use microsimulation in combination with the scenarios will be elaborated on.

Phase 4: analysing results and testing hypotheses

After analysing the empiric results concerning vehicle hours and vehicle loss hours it is possible to test if the hypotheses are false or true. Later on a second category of hypotheses can be tested with the help of the interpretation of the same data gathered from the MSTM. Two criteria for this interpretation can be distinguished: the change in traffic flow and the change in road network capacity.

Phase 5: getting empiric insights into the mobility of the future city with AVs

This last phase should answer the main question while several answers have been provided for the subquestions during the research. If the research, a first step into the quantification of scenarios with automated vehicles in the future city, already provides some reliable data, policy advice about mobility can be a given. Otherwise, some recommendations for further research will be necessary to develop policy advice.

1.5.3 Project relevance

1.5.3.1 Scientific relevance

There are plenty of large companies, such as Uber, Google, Volvo, Mercedes and Apple which invest a big amount of money in automated vehicles and even test them on the roads. Automated vehicles will have a large impact on mobility and on the urban environment (Milakis et all., 2015). Most studies take the technology of automated driving as a starting-point (BCG 2016; CPB 2015; KIM 2015; Milakis et al. 2017; Fagnant 2015), but it could be more interesting to take the city and its mobility as a starting-point. During the interviews, researchers of 'Plan Bureau Leefomgeving' (PBL), Transportation Research Institute in Hasselt (Belgium) and the Urban Futures Studio University Utrecht suggested the same manner in which this subject could be approached. The approach of taking the mobility in a city as a starting point for conducting scenarios is unique. This in combination with modelling the scenarios in accordance with the MSTM. Several scientists have advised to use such an approach. For example Rasoulie and Timmermans (2013) strongly recommend to shift from aggregate to more integral microscopic models of choice behaviour. This allows more integral policy performance assessments. They stated that the uncertain future scenarios represented in the discussion should not interfere with the plan of using microsimulation in combination with the scenarios. In the discussion this scientific debate has been elaborated. Furthermore, a leading article by Milakis et all. (2017) has been discussed Modelling Is recommended here, as this could provide more empirical data about first order implications (Figure 5). These implications have priority when the technology of AVs evolves. This problem is in line with the Collingridge dilemma concerning automated vehicles. This means that a lack of sufficient information about the new technology makes it impossible to predict the impact. However, when information about the technology is available in time, it will prevent high costs and give more control to use it. But when it is to late technology could be already so embedded that it will lead to wrong decisions (Collingridge 1980). The scientific relevance of this research is to find out if a microsimulation traffic model provides some insights into mobility with respect to automated vehicles in the urban areas. This research could be considered as a link between several insights into microsimulation and useful mobility advice, which leads to livable and sustainable cities substantiated by empirical data. By means of literature study, interviews with experts on the subject of future mobility and autonomous vehicles, four future scenarios have been conducted (qualitative). After this qualitative approach the development and the features of these scenarios have been translated into the MSTM (quantitative). The purpose of this paper is to provide useful empirical data about the use of AVs in the urban environment.

1.5.3.2 Social relevance

This research can be socially relevant, because it contributes to a more sustainable mobility in cities of the future. Cities have to deal with an increase of negative effects of urbanisation and globalisation. Quantitative results, which can be implemented in the city today to reach sustainable mobility in the future will help to solve societal problems, with respect to safety, living space, public health, energy consumption and environment. In contrast to other studies it will show us how the features of autonomous driving can contribute to the future mobility. With the help of the MSTM, empiric results try to give more insights into these effects of AVs. Carefully chosen features appropriate for each scenario help to achieve this.

Besides this, the results of the research could be used to advise policy makers or to form a bridge between automotive industry and policy makers. This research have been done in collaboration with Sweco and the University of Utrecht. Sweco's "mobility" department is wondering how they, as a consulting institute, can contribute to the development of mobility in the future and what the possible role of autonomous mobility will be.

2. Theoretical framework:

2.1 Automated vehicles

What possibilities will automated vehicles bring us in the future? This question is explored in the first part of the theoretical framework. This part shows several possibilities, but later on, when the AV's are modelled in S-Paramics, only the possibilities that are allowed by the parameters of the MSTM (microsimulation traffic model) are taken into account and will be further explored.

Currently, new entrants such as Apple, Tesla, Uber and Google have started to influence the automotive industry towards more ICT based solutions (Fagnant and Kockelman, 2015). Experts expect that the development of autonomous driving will go fast and that fully automated vehicles will reach the market between 2020 and 2030 (Underwood, 2014; Litman, 2014; Zmud et al., 2015). A research by Kyriakidis et al. 2015 explored the public opinion based on an internet questionnaire survey with 5000 respondents from 105 countries. 69% expected fully automated vehicles to reach a 50% penetration rate by 2050.

Several levels of automation have been developed. It is important to understand these levels and know which one is used in this research. First of all, a short explanation of the classification of the six levels of automation from 0 to 5 is given. These have been conducted by the Society of Automotive Engineers (SAE) International.

At the levels 0, 1 and 2 the human driver monitors the driving environment and controls all the driving tasks. At the other 3 levels the automated driving system monitors the environment and has the possibility to take control of all the dynamic tasks. It is only at level 5, which is fully automated, that the driver is not expected to check anything at any time during the trip. At the other levels, 3 and 4, the driver still needs to be available for occasional controlling (SAE International, 2014). As level 5, the final automation level, represents the most radical changes in the urban environment, micro simulation is used to determine the mobility of the future city (Figure 4).

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Figure 4 – This table summarises the levels of driving automation for on-road vehicles as devised by SAE International.

A second important aspect is that there are two sorts of automated vehicles, i.e. the vehicle, already called 'autonomous' and the connected vehicle (Bhat, 2014). An autonomous vehicle senses its environment and is able to navigate without a driver. Connected vehicles have got internet access, sometimes even wireless, in order to 'sense' their surroundings. According to Timmer and Kool (2014) a cost-effective and reliable automated vehicle will have to be a combination of both technologies.

Milakis, Van Arem and Van Wee (2015) have provided a paper, which shows the ripple scheme effect caused by automated vehicles. Every ripple is divided into categories, which are influenced by automated vehicles. These categories provide a guideline in order to go more deeply into the possible effects (Figure 5).

First of all, literature is used to conduct the scenarios. Later on, it has to be evaluated to what extent the empirical results of the MSTM contribute to the first, second or third order of the ripple scheme.

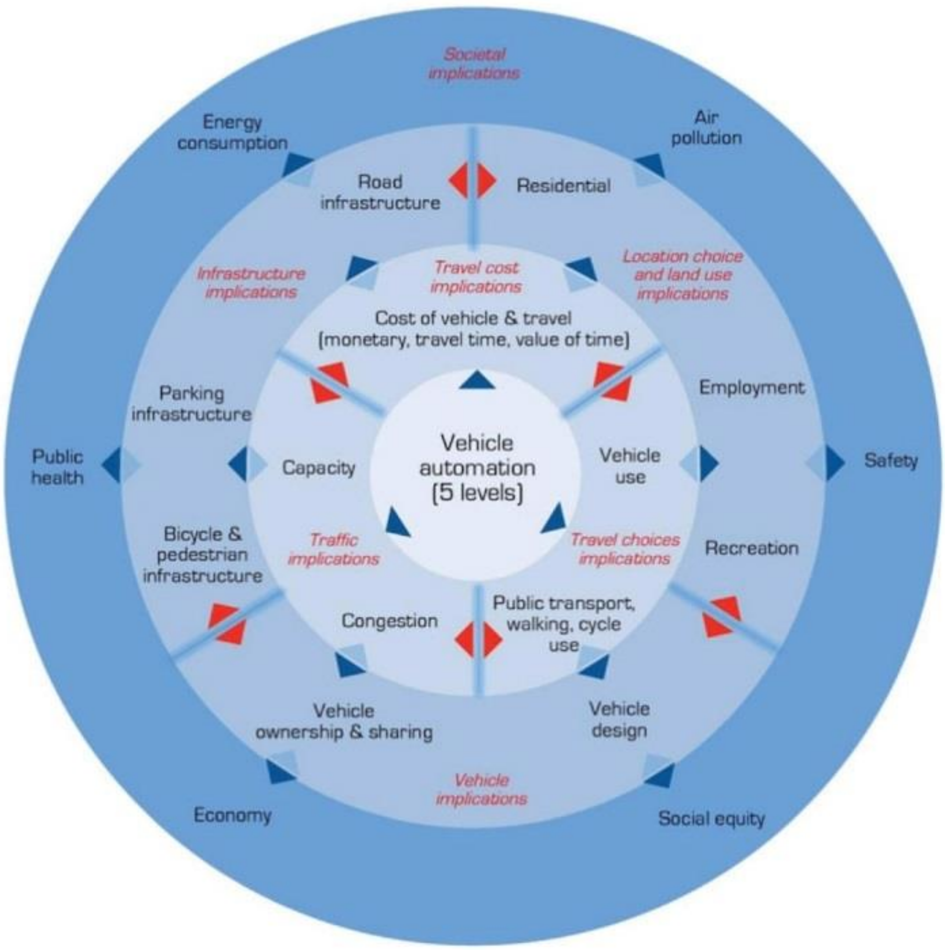


Figure 5: Ripple scheme of implications of automated vehicles. The inner ripples are influenced by the lower levels of automation from conditional automation and upwards (as defined by SAE (2014) fig..).The outer two ripples will be influenced as well (Milakis, Van Arem, Van Wee, 2015).

The first ripple exists of the following categories: travel cost implications, travel choice implications, and traffic implications.

2.1.2 Travel cost implications

To start with travel cost implications: these include travel time, value of time and monetary cost.

2.1.2.1 Travel time

According to some studies it is possible that traffic time will decrease, but that travel time will remain the same is more likely. Because Marchetti (1994) has found out that the average daily commuting time has always been approximately one hour (Marchetti's constant). People have based their living conditions on the available modes of infrastructural condition and transport in such a way that the travel time is always about the same. Important to mention here is the fact that traffic flow improvement and a reduction of congestion might lead to more vehicular traffic and again travel time remains the same (Fagnant & Kockelman, 2015; litman, 2015).

2.1.2.2 Time value

Time is one of the main values that will change significantly with the introduction of AVs. When the highest level of automation is implemented, comfort during the trip will most likely be increased, as work or recreation is possible. This causes a positive change in the value of time (Fagnant & Kockelman, 2015; Gucwa, 2014; Litman, 2015; Snelder et all., 2015).

2.1.2.3 Monetary cost

The last implication is about monetary cost. This will probably be decreased, because of the following two reasons. First of all, car sharing will be more common when using this type of transport (Fagnant & Kockelman, 2015; International Transport Forum, 2015; Johnson & Walker, 2016). The second reason will be the more efficient use of fuel, amongst others because of less congestions and a better flow (Bullis, 2011; Fagnant & Kockelman, 2015; Litman, 2015).

2.1.3 Travel choice Implication

Travel choice implication exists of three aspects: vehicle use , vehicle kilometres travelled (VKT) and choice of mobility.

2.1.3.1 Vehicle use

When AVs are introduced, the use of these vehicles will most likely increase, because of the comfort. When a vehicle is drives autonomously, the passengers can spend their time more efficiently as explained earlier (Fagnant & Kockelman, 2015; Gucwa, 2014; Litman, 2015; Snelder et all., 2015). According to Gucwa (2014) it might be very well possible that larger AVs will be designed in order to accommodate several activities, such as work.

2.1.3.2 Vehicle kilometres travelled

On the one hand VKT might increase due to the introduction of autonomous vehicles. A lot of researchers have come up with multiple reasons. First of all, there is the idea that more groups of people will be able to use this kind of vehicles, namely: disabled, elderly and inebriated people, children and people who have not got a driver's license (Brown et all., 2014; Fagnant & Kockelman, 2015; Hendrickson et all., 2016; Litman, 2015; Sivak & Schoettle, 2015). Several other reasons that could cause more VKT are the following:

- cars park themselves in cheaper areas outside the city (Fagnant & Kockelman 2015), due to a higher travel convenience (Fagnant & Kockelman 2015; Litman, 2015),
- automated vehicles will induce a new urban sprawl (Litman 2015),
- additional vehicle travel could be induced by a reduction of traffic congestion and of vehicle operation costs.

On the other hand also a decrease in VKT could be witnessed, because of the following reasons:

- first of all vehicles may be used more efficiently, as a result of e.g. car sharing (Fagnant & Kockelman, 2015),
- less problems in finding parking places (Brown et al., 2014; Bullis, 2011; Litman, 2015; Shoup, 2005),
- better infrastructure for pedestrians and bicycles, an improved urban experience in way of life (Litman 2015),
- improved automation of public transport (Litman 2015),
- the result of behavioral economics, the theory of which can also be applied to travelling and traffic (Grabar 2016).

2.1.3.3 Choice of mobility

The choice of mobility will be influenced by the same reasons as discussed above with respect to the automated vehicle: a higher degree of comfort, reduction of vehicle operating costs, congestion and of the time-consuming search for parking places. This might influence the choice of using automated vehicles more often. Reasons for different choices, e.g. cycling or walking: improvements for bicycles and pedestrians, due to a better infrastructure and improved automated public transport. Both Begg (2014) and Litman (2015) have come up with the possibility that although walkability and cycling conditions an increase in vehicular traffic can lead to a degradation in walkability and cycling conditions. Litman (2015) also came up with different reason why the use of AVs might be increased, namely 'on-demand' automated vehicles, a kind of new form of public transport.

2.1.4 Traffic implication

The improvement of the traffic flow will probably be further stabilised if all vehicles have been replaced. A lot of scholars share this idea. Due to multiple reasons the capacity will increase. First of all, AVs can use the car lanes and intersections more efficiently, because of swarm intelligence (Ingels et al., 2010; Kabbaj, 2016) and coordinated driving in convoys. This results in the possibility of a smaller gap acceptance between vehicles (Fagnant & Kockelman, 2015). Furthermore, because of a vehicle-to-vehicle communication AVs can anticipate, when they accelerate or decelerate. As a consequence, the traffic-destabilising shock waves are reduced (Fagnant & Kockelman, 2015; Musk, 2016). Besides this, there is another important application with respect to route choice. AVs automatically avoid congestions by rerouting with respect to livability (Grabar, 2016). Moreover**,** connectivity between vehicles results in real-time speed adjustments. This leads to a higher average speed. Finally, as stated before**,** the International Transport Forum (2015) expects automated vehicles to stimulate car sharing. Due to these implications, occupancy rates will increase and this will lead to less traffic. However, on the other hand, due to the positive effect of AVs on the traffic flow more people will use this form of transport. That is why it will result in more traffic.

2.1.5 Vehicle implications

As a result of automated vehicles the vehicle ownership is likely to decrease, because of car sharing. This also leads to a reduction in vehicles (Fagnant & Kockleman, 2015; Litman, 2015; Sliberg et al., 2012). Vehicle sharing also leads to higher occupancy rates**.** This reduces the average amount of vehicles per person (Brown et al., 2014). When automated vehicles become available, automated taxis will cost no more the ownership of a vehicle, according to Johnson and Walker (2016).

2.1.6 Infrastructure implications

The road network, which automated vehicles use, should be hugely transformed. Especially when all the automated vehicles are connected to the cloud and all the information can be sent to the cars, the infrastructure can do without traffic lights, cluttering signs and other visual signals that influence the driver's behaviour. Also real-time information from the infrastructure itself can be sent to the AVs through vehicle-to-infrastructure communication. Finally**,** the width of the lanes can be narrowed due to more efficient driving (Fagnant & Kockelman, 2015). However, Gucwa (2014) has come to the conclusion that lanes should be widened with respect to the increased size of the AVs. This as a result of having created more passenger comfort.

Apart from the road infrastructure, the parking infrastructure should be changed drastically as well. First of all, the connectivity between cars and parking infrastructure will lead to an optimal occupancy of car parks and can reduce the amount of required parking places (Brown et al., 2014; Bullis, 2011; Litman, 2015; Shoup, 2005). Secondly, AVs will be able to park themselves anywhere. With respect to cost efficiency, the car parks could be situated in the peripheries. As a result, those in the urban environment will become available for other use (Anderson et al., 2014; Begg, 2014). Thirdly, due to ride and car sharing services, the amount of parked cars will be reduced. They will be use more intensively (Claudel & Ratti, 2015; Fagnant & Kockelman, 2015; McDonald & Rodier, 2015). Lastly, because of exact driving possibilities and the driverless parking ability, AVs need smaller parking spaces (Fagnant & Kockelman, 2015). However, with respect to Gucwa's (2014) prediction about the increased size of the vehicles, this theory could be curbed like the width of the roads.

2.1.7 Location choice implications

As stated earlier, people have more or less had the same average travel time all over the world each day for decennia (Marchetti, 1994). Because of this phenomenon and because of that fact that automated vehicles may lead to more efficient traffic congestions will be avoided and people will be able to increase their travel distance and keeping the same travel time. In the future residential, employment and recreational locations are likely to change. A new sprawling city could be the result (Fagnant & Kockelman, 2015).

2.1.8 Societal implications

It is likely, that the use of automated vehicles will lead to a reduction in emissions. First of all because AVs will probably go hand in hand with the electrification of the transport sector (Fagnant & Kockelman, 2015). Secondly**,** AVs will probably be used more efficiently (Bhat, 2014; Fagnant & Kockelman, 2015; Litman, 2015). Conversely, due to an increase in car size and weight, the use of energy might increase (Gucwa, 2014).

Travel time reduction with respect to car parking and an increase in car and ride sharing can cause a decrease in energy consumption (Brown et al., 2014; Bullis, 2011; Claudel & Ratti, 2015; Fagnant & Kockelman, 2015; Litman, 2015; McDonald & Rodier, 2015; Shoup, 2005). Besides this**,** car rental will be more common with AVs and rightsizing of vehicles might lead to a reduced energy consumption (Hopper, 2016).

At the moment, approximately 93% of all car crashes are mainly due to driver's errors (National Highway Traffic Safety Administration, 2008). With the introduction of automated vehicles scholars agree that the safety of driving can increase (Fagnant & Kockelman, 2015; Litman, 2015).

Car travel options will become more affordable for every layer of the population. This because of the decreased operating costs as a result of better car sharing services and more efficient driving. So social equity is likely to increase.

The economic benefits for society with respect to the introduction of automated vehicles can be found in the reduction in infrastructure investments, due to narrower car lanes, and to the fact that signs and protection measures are no longer necessary (Silberg et al., 2012; Wagner et al., 2014). When AVs have penetrated the market for almost 100%, the costs of vehicle crashes and congestions could be reduced considerably (Fagnant & Kockelman, 2015). Besides the costs, also health matters will benefit, when there are less traffic accidents and less emissions. However, as was stated before, there is a chance of a negative effect with respect to more emissions as a result of an augmented use of AVs. Another more psychological negative effect could be the disconnecting of users from their surroundings because of the encapsulated character AVs can have, this could lead to social isolation.

The problem of congestions could be divided into two groups. Fagnant and Kockelman (2015) noted that AVs will lead to less congestions, but on the other hand, according to Litman (2015) this effect will probably not arise, because of an induced demand of vehicle use.

The introduction of autonomous vehicles may change the entire mobility 'landscape' in our cities. That the major part of our mobility will be provided by clean, electric, autonomous vehicles may not be uncertain any more. But how will this affect major factors in the travel patterns, one of the most important ones of being the change in the value of travel time. This again is related to travel patterns, on which ICT will have a strong influence. The way our society will develop in relation to these effects is yet uncertain but more insight is needed to define paths towards the 'desired' cities.

2.2 Scenario building background

To bring structure into the wide variety of possible 'futures' for mobility in cities for this research an approach using scenarios is chosen.

In this chapter the scenario-building theory is summarised with the intention to distillate interview questions and plausible future scenario's with respect to the effects of autonomous vehicles.

If predictions of unknown forthcoming events are made, scenario analyses can play a major role in addressing the challenges with respect to the future in an integrated, structured and policy-relevant manner (Swart et al., 2004). Börjeson et al. (2006) has stated that three scenario categories can be distinguished. These are based on principally important questions for the use of scenario analyses and come down to the following:

- What will happen?
- What could happen?
- How can a specific target be reached?

The categories that are linked to these questions are: predictive, explorative and normative scenarios. Each category is divided into two types.

- The first category (predictive scenario) can be divided into forecasts and what-if scenarios.
- The second category (explorative scenario) also consists of two types: external and strategic scenarios.
- The last and third category (normative scenarios) includes persevering and transforming scenarios.

Each of these categories has its own features and should be used in different situations. First of all, it is important to choose the most useful type of scenario analysis for this research. The purpose of conducting scenarios is to create optimised prospective situations concerning mobility and infrastructure and to see how automated vehicles can contribute to the realisation of ideal circumstances. At this moment however, this will probably be unattainable if we take the ongoing development into consideration. The transforming scenario seems to be the most useful one to deal with this problem. According to Börjeson et al. (2006), this scenario analysis type can help answering the question how to optimise the circumstances. In order to deal with this, a reverse-forecasting technique, which is known as back casting have been applied. With respect to mobility and infrastructure in urban areas. When found out which scenario type can be used, it have been constructed by adopting a detailed step-by-step methodology. There are lots of methods for the process of scenario building (Chermack et all., 2001), but in most methodologies a structure is perceived, consisting of six phases. These are chronologically arranged: setting the scope, challenging perceptions of scenarists, generation, integration, reflection and application. In this research the phases will be elaborated on.

2.2.1 Scenario building methodology

If scenarios will be built it is possible to construct a step-by-step methodology. There are a lot of methods for the process of scenario building (Chermack et all., 2001). Based on literature, the following methodology has been established. Each step will be shortly explained with respect to its relevance ~~is~~ and its influence on the process (Figure 6).

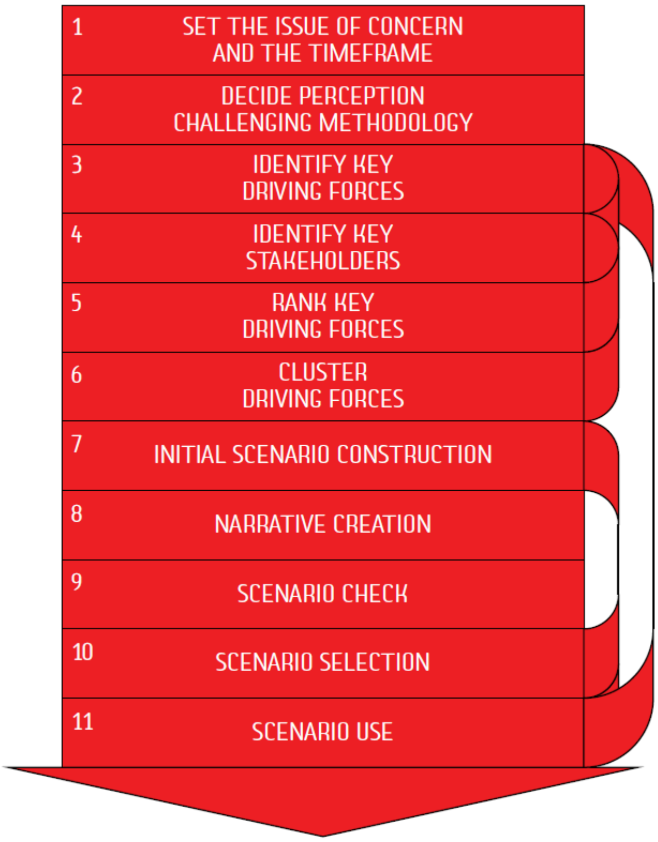


Figure 6 – Scenario developing scheme (source: the mobility/livability revolution by Mick de Waart).

The *first step* of scenario building is *determining the issue of concern* (Chermack, 2007; Godet, 2000; Ratcliffe, 2002; Schwartz, 1991; Wright et al., 2013; Wright & Goodwin, 2009) and after that, placing it within a time frame (Schoemaker, 1995; Wright et al., 2013). The purpose of this first step is to make explicitly clear, what the reason of scenario building in this context is and also what the time frame will be in which the scenarios can be executed. It is important to properly address the issue of concern. Otherwise the whole project might fail (Perrow, 1999). In order to guide the process with respect to the specific context, explicitly mentioning the time frame is very important. More extreme scenarios need to be conducted, when it is related to a longer time frame with larger uncertainties.

The *second step* is *to challenge the perception of scenario building participants*. In order to make scenarios more diverse and thus more reliable, the creativity of the human mind should be triggered. It might be important to reinforce this by introducing a special method. At the same time this could prevent people from having wrong or narrow perceptions of the issue of concern (Wright and Goodwin, 2009). When building scenarios, it is important to keep the principle of what one would like to achieve at the back of one's mind and to explore an area of possible future as broad as possible. Chermack (2007) and Uotila et al. (2009) came up with possible techniques, which ensure of ensures participants to be aware of their subjective perception and to challenge their espoused theories. Chermack (2007) and Wright & Goodwin (2009) introduced the technique of "remarkable people", people who have a different view or different expertise on the issue of concern. Chermack et al. (2001) and Mietzner & Reger (2005) introduce systems to stimulate the participants to think more holistically. Wright & Goodwing (2009) found a way how to influence the issue of concern by a role-play or by making people play the parts of actors who would be involved in the scenarios. The technique by Vervoort et al. (2015) includes a pluralistic present. Participants have to create individual scenarios conducted by their own subjective image of the present. Finally, Salewski (2012) introduces scenario building based on hallucinogenic drugs, which can open up new pathways in the brain, so that creativity can be liberated.

The *third step* is *to identify the key driving forces influencing* the issue of concern (Arcade et al., 1999; Chermack, 2007; Godet, 1987; Phelps et al., 2001; Ratcliffe, 2002; Schoemaker 1995; Schwartz, 1991; Wright et al., 2013). Driving forces can be events or trends that might influence the issue of concern. The basis of the eventual scenario is formed by all the driving forces together. When more driving forces are found, it is possible to go back to this step later on and iterate this.

The *fourth step* is *to identify the key stakeholders* (Chermack, 2007; Schoemaker, 1995). All the stakeholders that could influence the issue of concern or the driving forces will be identified in this step. When establishing the development of external factors, it can be relevant to know in what way key stakeholders are involved, directly or indirectly. A brought range of stake holders needs to be identified.

Step five is about *ranking the driving factors* (Chermack, 2007; Schwartz, 1991; Wright et al., 2013; Wright & Goodwin, 2009). In this step the driving factors need to be judged on both impact and likelihood (Schwartz, 1991). In all the scenarios the height and probability of the impact of the driving forces should be mentioned. The low impact driving forces only appear in scenarios when they fit in by chance. The basis of the scenarios will be determined by the low probability driving forces.

The *sixth step* is *to cluster the driving forces* (Wright et al., 2013). In order to form clusters, synergies or causal relations between driving forces should be investigated. The driving forces that are ranked as 'unlikely to happen' will most probably be limited to just a few clusters or even only one. Those that are ranked as having a high degree of certainty will be likely to appear in more clusters.

The *seventh step* consists of *the initial construction of the scenarios* (Arcade et al., 1999; Chermack, 2007; Wright et al., 2013; Wright & Goodwin, 2009). This one will be used to form internally coherent scenarios after having clustered the driving forces together.

The *eighth step* is *to construct a narrative structure for the scenarios* (Chermack, 2007; Ratcliffe, 2002). Here, a narrative structure will be created and the scenarios will be further elaborated. If necessary, diving forces can be added to complete the causal chains.

The *ninth step* is *to check the scenarios of plausibility.* This means it should be possible to actually unfold the scenarios as described (Chermack et al., 2001; Heinecke & Schwager, 1995; Wilson, 1998).

With respect to this, there are four aspects that should be taken into consideration.

Differentiation: this means that all the scenarios should be different with respect to the issue of concern. Is the outcome just a variation or are the really different from each other? (Chermack et al., 2001; Heinecke & Schwager, 1995; Wilson, 1998).

Consistency: the combination of scenarios should form a coherent part with respect to the logic on which the scenarios are built (Börjeson et al., 2006; von Reibnitz, 1992; Wilson, 1998).

Decision-making utility: the scenarios should offer a possible solution in dealing with the issue of concern. At least the scenarios should be helpful. (Chermack et al., 2001; Heinecke & Schwager, 1995; Wilson, 1998).

Novelty: The issue of concern should be seen from a new perspective with the help of the scenarios. The idea is that different possible outcomes are shown, which are likely to be fully considered (Chermack et al., 2001; Heinecke & Schwager, 1995).

The *tenth step* is *to flesh out scenarios that do not perform in all subdivisions of step nine*. Even after having completed this step it is still possible to redo a part of the process again if necessary.

Finally, the *eleventh step* is *using the scenarios*. When the scenarios are used, the elaboration will be monitored and again the process could be repeated, because using the scenarios might give rise to new possibilities.

2.3 Traffic model background

A traffic model is a computer model, which gives an insight into the present and/or future traffic and transportation flows. The calculations usually take place on the basis of a network of infrastructure and traffic counts. Some models also demand supplementary data, such as information about demography and social aspects

At this moment there are three categories of traffic models available: microscopic, mesoscopic and macroscopic

The following clarification might be useful here:

-Microscopic
The basis of microscopic models is the smallest unit (a vehicle). Rules of conduct are taken into account here.

-Mesoscopic
The basis of mesoscopic models are units consisting of several vehicles within which elements are considered homogenuous.

-Macroscopic
The basis of macroscopic models can be observed in intensities and densities with respect to the links in the infrastructure.

Statistic models

Traditionally seen, traffic models are static. They do predict intensities of the roads and compare this to the road capacity, but e.g. the consequences of traffic jams regarding have not yet been taken into account. These models are especially suitable to make calculations on a macro level, for example to calculate the effects of constructing a new motorway or residential areas.

Dynamic models

Dynamic traffic models allow for the restrictions of the road network capacity and the consequences of e.g. traffic jams. These models are suitable to get an insight into the effects of e.g. the reconstruction of an intersection or constructing a new traffic lane. Furthermore, these dynamic models can be used to test the settings of traffic lights. Vehicles can be imitated as if they were real ones (figure....). Well-known dynamic software packages are Vissim, Paramics and Aimsun.

2.3.1 The microsimulation traffic model S-Paramics

For this research the MSTM S-Paramics is used that is why some more information about this specific model is provided. Sweco can see to it that a large part of the road network of the road network of Eindhoven is included in S-paramics, this is why the model of Eindhoven is used in this research. In the past, Sweco has carried out traffic analyses as a basis for the development, calibration and validation of the traffic model. The purpose of the traffic model is to assess and compare different road alternatives and different scenarios for development of areas for dwellings and areas for industry and so on. The main purposes of data collection are twofold: 1) collect the traffic data to calibrate the base year traffic model; 2) collect social-economic data to estimate the current traffic demand (and is calibrated by the current traffic data) and to forecast the future traffic demand.

The sources of traffic data are among others: roadside detection (e.g. Induction Loop Detectors, Infrared Detectors, Video Cameras etc.), floating car data (e.g. Probe vehicles, GSM and GPS data etc.), on-site counting (for both intersections and road sections).

The social-economic data to determine the origin and destination of the traffic, including traffic from adjacent areas and transit traffic, will collect social-economic. These social-economic data is the input data for the traffic demand model development.

The traffic model is used to describe the existing traffic, forecasts of the future traffic, the consequences and the recommended incremental improvements. By changing the input of the vehicle parameters or infrastructure the output of the model has to be analysed. The analyses of the model are explained in Vehicle Hours (VH) and Vehicle Loss Hours (VLH). This outcome gives information about the changes in road network capacity and traffic flow. Later on in this research it is explained why it is of importance to revalue the vehicle parameters and what exactly VH and VLH include.

Figure 7: Screenshot of the MSTM S-Paramics

2.4 Traffic flow in urban areas

All aspects of the quality of life are significantly affected by urban traffic congestions especially in larger cities. Reducing traffic congestions, delays, emissions, energy consumption and improving safety are important. Parameters of vehicle behaviour, such as occupancy, traffic volumes, travel speed, etc. are needed to give information and predictions about travel time and subsequently also about optimal regulation of road traffic on all types of streets (Stathopoulos & Karlaftis 2001). At the moment, giving travellers accurate information regarding travel time effects and route choice decisions leads to an improvement of network efficiency. The right use of the above mentioned parameters helps to meet the goal of reducing congestions, give drivers the ability to improve route and departure time choices and decrease travel time (Stathopoulos & Karlaftis 2001). In the future the parameters can be used to navigate AVs and improve traffic flow and network capacity (Fagnant & Kockelman, 2015 Litman, 2015). Resetting the behaviour of the vehicles by using the MSTM S-Paramics, can result into new amounts of VH and VLH. Later on, it will be possible to interpret VH and VLH into traffic flow and road network capacity.

3. Developing scenarios

3.1 Interviews with experts as input for scenarios

Interviews with professionals working on the topic of automated vehicles show that expectations are still widely varied. In the interviews the focus was set on level 5 of automation. On the level of local communities there are ideas that lead to ideas about a considerable improvement of city life. For example, in the city of Eindhoven, the belief in the development of automated vehicles seems to be influenced by actual mobility policies and financial scope. For instance the decline of parking fees is seen as a serious disadvantage. The introduction of autonomous vehicles up to level 4 is expected to be commonly accepted within 10 years. Level 5 is expected to be introduced in a later period of time.

However, cities want 'to be ready' for autonomous vehicles and are seeking possibilities to offer (road)space for experiments and test sites.

The positive effects for the livability of the city seems not to be very widely recognised. Professionals of the PBL (Planbureau Leefomgeving) show some skepticism towards autonomous driving and emphasise the step-by-step introduction. Technical development and regulation are important issues to be addressed and this may slow down the introduction of automated vehicles.

In the field of science there is a positive attitude towards the development of automated vehicles (for instance Delft, Eindhoven, Utrecht and Hasselt, TNO, PBL and Sweco) Universities are working on the quantification of travel time and time loss caused by congestion as well as improved traffic safety. Also universities are working on the implementation steps and develop views on road networks for situations with mixed (automated and non-automated) vehicles as well as situations with only level 5 automated vehicles. The 'mixed' situation may prove to bring more problems than a future with only full automated vehicles. The rapid introduction of ICT and Artificial Intelligence in daily life is – as for instance seen by the University Utrecht – a catalyst for 'mobility as a service' systems facilitated by automated vehicles.

The sharing of vehicles, which can be optimally used in combination with automated vehicles, may be a strong factor in the introduction in cities.

Last but not least the ideas of manager of sustainable transportation Lauren Isaac, regarding automated vehicles. She emphasises the positive effect of 'driverless cars' on mobility. In the near future it is expected that people show disbelief, when considering driving conventional cars. She has pointed at the possible overflow of the traffic system caused by the multitude of new trip possibilities.

3.2 Building the scenario

In this paragraph four (extreme) opposite scenarios are built as a result of the interviews with experts and by applying the scenario building methodology as described in paragraph 2.3. The scenarios form a basis for the next step in the research: quantifying the expected autonomous vehicle behaviour for modelling within a micro simulation environment. This is of significance, because the focus of this research is introducing self-driving cars in the microsimulation traffic model. The scenarios can be seen as a tool that makes it possible to find the right value for each parameter. They have been developed with the assistance of some of the scenario building methodologies, based mostly on the knowledge of experts and interview sessions. In the end a four-based scenario scheme has been conducted. The following steps explain how these scenarios have been established.

Step 1: Setting the issue of concern

The issue of concern in this building process is developing scenarios that represent the mobility of the future city to show the possibilities of automated vehicles with a microsimulation traffic model. The characteristics of the scenarios will be used to set the parameters of the microsimulation traffic model. The timeframe within which these scenarios could become reality will be between now and the moment that automated vehicles are dominating the street view. After having analysed the future mobility with respect to different scenarios by using the microsimulation traffic model, it was possible to show the advantages and disadvantaged of AVs. These are explained with respect to changes in road capacity, which are expressed in different values. That is why it is important to reflect the scenarios in the different parameters that are adaptable in the microsimulation traffic model. The parameters are the following: the influence of acceleration, deceleration and speed limit on the traffic flow, the behaviour of the vehicle types, expressed in aggression and awareness, the vehicle features, such as minimum gap, gap acceptance and mean headway and last of all the route choice, expressed in familiarity, cost factor and the route choice formula.

Step 2: Deciding on a starting point

In order to build the scenarios in this research a limited number of techniques, have been used. Before constructing the scenarios, interviews were held with insiders and outsiders in order to create a wide range of information with respect to the scenarios. During the development of the scenarios, a building scheme was taken into consideration and brainstorm sessions with experts gave shape to the several possibilities. The sessions were informal, because this saved some time and as a result there appeared to be more room for the participants' creativity. This has also led to a larger variety of the scenarios.

Step 3: Identifying key driving forces

In step three the driving forces have been identified. The scenarios have become rather extended and, later on, will have to be narrowed down to features that can be translated into the parameters of the microsimulation traffic model (MSTM). The key driving forces will be found in the reasons of mobility development concerning the MSTM and have been discussed during expert sessions and interviews. This has resulted in the following key driving factors, which could be represented in the MSTM, when modelling the future mobility of the city**:** change modification in activity patterns, change modification in motivation as far as travelling and changes in possibilities for movement are concerned.

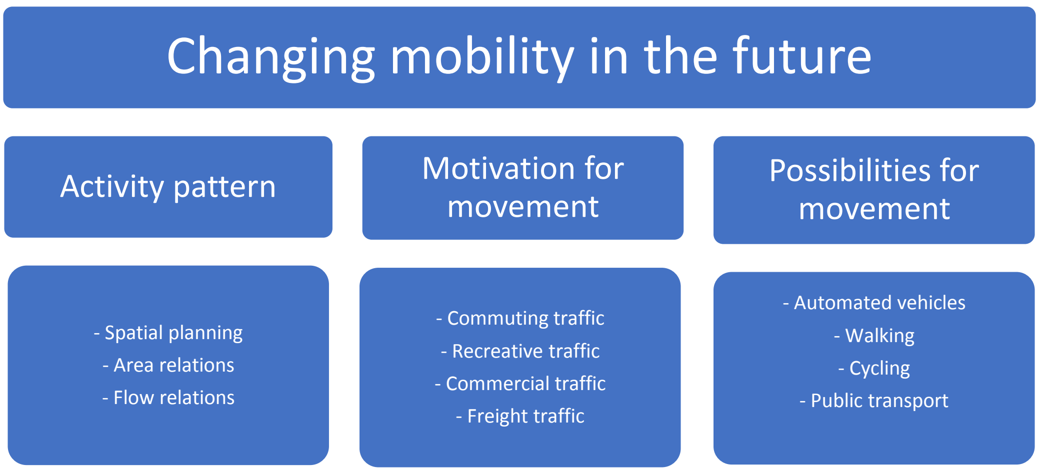


Figure 8 – Identification of driving forces.

Step 4: Identifying key stakeholders

The following key stakeholders can be identified: new residents, elderly, young families, public transport sector, tourists, students, highly educated, entrepreneurs, long-time residents, expats, and governmental institutions. All these stakeholders will influence the mobility policy and, to a greater or lesser extent, the key driving factors.

Step 5: Ranking key driving forces, Step 6: Clustering the driving forces

In step 5 the key driving forces should be ranked according to likelihood and impact. In step 6 the synergies and causal relations between the driving forces should be explored and after this clusters should be made. However, from this point onwards the scenarios conducted for this research deviate from the scheme. Instead of making the 'likelihood-and-impact-scheme', attempts to find a dimension a long the axis have been made with the help of experts and information obtained during interviews and from literature. This brings the process to steps 7-10

Step 7: Initial construction, Step 8: Narrative creation, Step 9: Check scenarios, Step 10: Selection

In steps 7-10 the four-based scenario scheme has been finished by an iterative process. Different dimensions have been conducted and after every new dimension scheme the possible scenarios have been discussed with intern and extern experts on the field of mobility. Step 7 till 10 are directly linked to each other and could be better described as one step, because the process of giving feedback and acquiring the definitive scenario can be seen as one step.

The dimensions have been ordered along the axis to get to the different scenarios. This is the usual way to conduct scenarios. The dimensions should be chosen in such a way that they cover all the drivers of the scenarios. For example, an increased collective society will probably lead to less mobility, due to shared mobility, more connectivity and less variation in driving style. For this scenario scheme two dimensions have been placed along each of the two axes one vertical one horizontal. This has led to four scenarios. These are the result of the mix of two extremes of the dimensions.

From this point onwards, the scenario building methodology has slightly deviated, as a more suitable iterative approach has been adopted. In this iterative approach, the steps 7 to 10 are merged and with expert judgement, the results from the interviews and investigated literature executed. For the construction of dimensions, two opposite dimensions are found to be the most suitable within the scope of this research. This leads to 4 scenarios. In this iterative process six different possible and suitable dimensions are found:

- high tech – low tech
- connected – unconnected
- traditional behavior – new behavior
- car ownership decrease – car ownership increase
- individual – collective
- efficiency – experience

Many of these dimensions have been tried in different combinations and it has been investigated if the developed scenarios cover the issue of concern. After this process the dimensions that cover this issue of concern the most are individual – collective and efficiency – experience.

3.3 Overview of the scenarios

As a result of the described work method four scenarios have been developed:

1) The Modernist city
2) The Pleasurable city
3) The Intelligent city
4) The Comfortable city

Figure 9 shows a visualisation of the categorisation along the vertical-axis (efficiency versus experience) and horizontal-axis (individual versus collective). A more detailed and vivid characterisation for each of the scenarios is provided in paragraph 4.4.

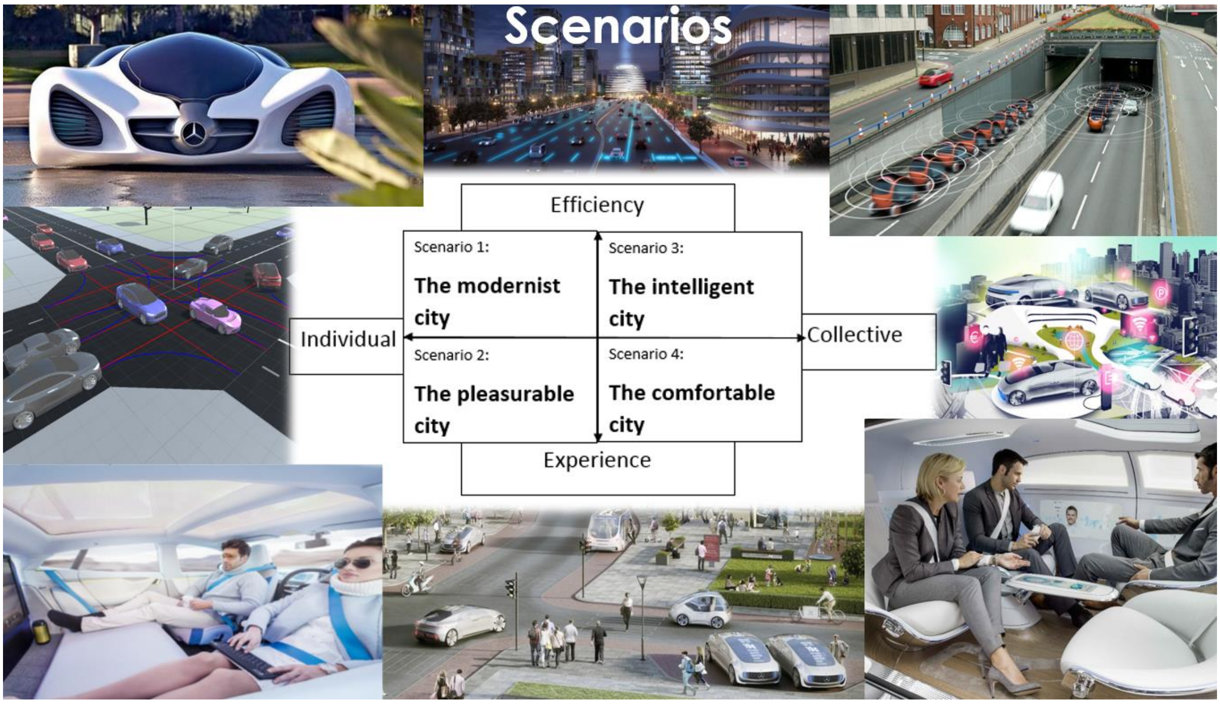


Figure 9 – Overview of the four scenarios for autonomous vehicles and the city of the future.

3.3.1 The two dimensions

The dimensions which will cover most possibilities of the future mobility in the urban areas are individual verses collective and efficiency verses experience. A short explanation is given with respect to each of the dimension.

3.3.1.1 Individual vs collective

At the individual side of this dimension people arrange their mobility independently. This means that they possess their own automated vehicles and show conventional behaviour while driving way. The vehicles are not connected. The collective side of this dimension shows the opposite. No one possesses a vehicle of his or her own. Only shared mobility in the urban areas is an option. All vehicles are connected to one system and operate together. The driving style and the behaviour ~~is~~ are advanced and the society is high tech.

3.3.1.2 Efficiency vs experience

Efficiency within this dimension is usually meant to indicate fast traffic. The mobility of the city is focussed on getting people as fast as possible from their place of origin to their place of destination, even at the expense of the livability of the city. The opposite of efficiency is the experience of the mobility, as a result of which traffic may have to slow down. The livability is important and has to be improved by offering more comfort for pedestrians and cyclists in the urban area.

3.4 The scenarios

The narrative of each scenario contains of a description of the mobility 'landscape' and a characterisation by using five main indicators. The scenarios are built on the basis of the extremes of the two dimensions. First of all, the dimensions will be explained.

3.4.1 The modernist city

In this scenario fast traffic is one of the backbones of urban policymakers. About 15% of the citizens share their mode of transport and connectivity between vehicles is restricted. All inhabitants have their own low tech vehicle. Vehicle behavior is expected to be within the low autonomation region. The behavior of autonomous vehicles is therefore more comparable to the current state of autonomous vehicles than to future full-autonomous vehicle behavior. The driver is still in charge of his own behavior like the aggression and awareness of the vehicle. Also route choice is flexible. The mobility in the city is built around and for autonomous vehicles, pedestrians don't have the attention and space they want. Travel times for vehicles are optimised.

Table 2 – Summarised characteristics for the modernist city scenario.

Slow traffic	**Fast traffic**
Partly Shared mobility	Only shared mobility
Unconnected	Connected
Traditional behavior	Advanced behavior
Low tech	High Tech

Maartje's future:

In the city where Maartje lives, you never get lost. The city is divided into blocks and every street is straight. Everything is very clear. Maartje lives outside the city centre. She prefers to live there, because her automated car can be parked in front of her house. It only takes her one minute to get to a 6-lane road. In her house you do not hear any sound from the road, because all the cars are electric and automated. With ~~the~~ sensors on every car they monitor each other. Accidents hardly ever happen. Only pedestrians and cyclists have to pay a bit more attention to the traffic. It is not possible to cross the main roads. Almost every family uses an automated car. It is even possible for the children to go to school by car without any of the parents accompanying them. The automated car has really become an indispensable device in every household. This also goes for Maartje. While driving on the dual carriageway it is allowed to drive 100 km/h, but the car itself knows the speed limit. Sensors on the street monitor if a route is crowded and send the information to AVs. They show you an alternative route, if necessary. Maartje is drinking coffee and reading a paper, when a message pops up, asking her if she wants to avoid a congestion. She decides not to accept it, because she is in a hurry and the detour will probably take a rather long time. She is lucky and with almost no delay she reaches the office/her destination. After she has got out of her car in front of the office in the city centre, her car is parking itself in one of the big parking garages. Some people share their cars, but Maartje's car is brand new and she wants to be careful with it. About 15% of the inhabitants share their cars with the help of an application on their phone. The boring company of Tesla has provided a few underground tunnels in order to travel fast from one side of the city to the other. But the main mobility movements take place aboveground. After work Maartje goes to piano lessons on the other side of the city. That is why she uses one of the tunnels. In 10 minutes she arrives at her destination. After the lesson she goes home and has some food delivered to her house. It is very common nowadays to have your food delivered every day. You can order almost all kinds of meals. It is delivered by an AV and arrives very fast.

3.4.2 The pleasurable city

In this scenario the mobility of the city is designed to achieve a pleasurable experience for the inhabitants. In the city it is attractive to walk and cycle because traffic moves at low speeds. Every form of mobility form is shared. Around 25% the road-infrastructure is downgraded to create additional space for recreation within the city environment. The model split shifts towards more use of (electric-)bicycles. With augmented reality the trip can be made even more enjoyable and passengers are able to work and/or relax during their travels.

Table 3 – Summarised characteristics for the pleasurable city scenario.

Slow traffic	Fast traffic
Partly Shared mobility	Only shared mobility
Unconnected	Connected
Traditional behavior	Advanced behavior
Low tech	High Tech

Future Adrie's future :

In this nice looking old city centre Adrie lives on the second floor of an apartment alongside the canal. Since a few years everyone has got cars that park themselves special garages. There is-possibility to sit in the front of his house adjacent to the widened sidewalk. Today Adrie is free from work and wants to test his new e-bike. He shares the e-bike with his neighbour. It is the first time he shaes a vehicle together with someone who is not part of his family. Adrie shares his autonomous car only with this wife and brother who live in the same city. He gets his e-bike from a special public charging box, where he and his neighbour rent a place. While biking on the bike lane a brand-new Mercedes E8 passes him on his left. This automated car is very luxurious and expensive. He hopes he can buy one himself one time. In the meantime, he is waiting for a traffic light. Nowadays, these are connected to the vehicles using this road, as a result of which the waiting time is reduced. When Adrie crosses a road he does not have to be scared anymore for accidents. All the AVs stop automatically. But the fines for crossing the road without permission are expensive. This in order to prevent the AV's from having to stop too often. Adrie has to wait for the self-driving tram that is passing by. Despite the fact that most of the public transport is now driverless, it works almost the same in comparison with the old system when there drivers were still needed. These days, Adrie doesn't use the public transport very often. He can work and have meetings in his own car now. There is no more waste of time because of travelling of traffic jams. He stops biking and parks his e-bike near a park. It was possible to give this park a very spacious lay-out, as parking places are no longer needed here. In the special parking garages vehicles can be stalled very closely to each other. The garages also work like a sort of enormous city-battery. You can even earn feed the surplus energy back into the power grid in return for a profit. After Adrie has visited the park he goes to Albert Heijn. Sometimes he has his shopping delivered, but it often takes a while before they arrive and besides this he likes to shop and choose the best products. On his way back home, Adrie notices all the public parks and gardens in the city. It looks really nice. On the sideways a lot of children are playing on fields of grass. His neighbour sends a message, asking if he can use the e-bike in half an hour, because he has forgotten something at the store. Adrie takes the shortest way back home, puts the e-bike in the charging box and starts cooking.

3.4.3 The intelligent city

In this scenario efficiency, collective transport and information is important. Citizens do not own vehicles, but can order vehicles that arrive at their front door. Autonomous vehicles are the preferred mode of transport, because they are the most convenient and fastest. The vehicles and road network are super intelligent and technology ensures mobility is safe and traffic flow is fluent. All the cars are connected to each other and work together. With *a drop on and drop off system* every location is easily reachable. Additional infrastructure for pedestrians and cyclists is not necessary because, this way of transport is slow and considering the fast moving autonomous vehicles, more dangerous. Through efficient use of vehicles, less parking space is required and thus a lot of space becomes available for e.g. recreational parks.

Table 4 – Summarised characteristics for the intelligent city scenario.

Slow traffic	**Fast traffic**
Partly Shared mobility	**Only shared mobility**
Unconnected	**Connected**
Traditional behavior	**Advanced behavior**
Low tech	**High Tech**

Daan’s future:

Today Daan wants to visit Amsterdam. He lives in Delft and takes the hyper-speed-train to Amsterdam Central Station. He does not have to worry about being in time. At really busy moments he gets a notification that he should take a train earlier. Later on when he has got out of the train the application on his phone guides him fast along the central station of Amsterdam to the shared and automated taxi hub. These taxis are small and compact vehicles for a maximum of two persons. They operate in convoys, following each other on the main road. They can bring Daan to almost every location in the city by leaving convoy and continuing on the sideways. In the city the main roads are isolated from vulnerable road users by fences or underground pedestrian tunnels. The AVs are allowed to drive of 120 km/h in the city and outside the city even faster. Daan wants to go from the Central Station to the Rivierenbuurt. It only takes him 5 minutes to get there. After he has left the main road, he is dropped off in front of a friend’s house. While they are chilling, Daan talks about a new device, which is much nicer than the previous virtual reality glass. They can use it to have a meeting for work, but also to play games. Daan becomes really enthusiastic about the game and decides to order it now, because they would like to play it that very afternoon. They order the device via internet. One hour and a half later it is delivered by a drone, which comes from one of the gigantic distribution centres ~~on~~ in the countryside. Daan and his friend install the game and go to the park, which is 2 kilometres away to play it. They do not want to spend a long time travelling and decide to take shared Segways. In a big city like Amsterdam it is very common to use Segways or e-bikes, because special lanes have been realised for bikes. They leave their Segways at the hub at the edge of the park. When they finish the game, they walk back home. During their way back they walk along places where old parking lots used to be. The space is now used for traffic. The road is divided into several small lanes. The centre of the road can be used for very fast automated vehicles. The outer lanes are meant for the slower ones. The sidewalk, where Daan and his friend, are walking, is constructed for pedestrians a cyclists. A lot of hop on and off hubs have been realised so everyone can. reach their destination as soon as possible. Despite of the fact that a lot of products are delivered from the giga distribution centres or are acquired via 3D printing at home, some stores are still physically present at the steeds. Especially when clothes or other things are concerned, people would like to have a look at it themselves. When Daan and his friend come home, they order some tasty fresh ingredients for a good meal, which Picknick, a supermarket in the neighbourhood, delivers every day.

3.4.4 The comfortable city

In this comfortable city, the focus lies on experience and comfort of travel. Besides shared autonomous vehicles, other modes of travel are conveniently used. Every mobility form is connected and use of it is regulated by a mobility service. Vehicles are made to experience a nice trip by providing entertainment with augmented reality or the possibility to have work meetings. The vehicles avoid crowded places and shopping areas. This enhances the liveability of the city. The trips may take slightly longer when compared to the past, but this is compensated through a higher level of service.

Table 5 – Summarised characteristics for the comfortable city scenario.

Slow traffic	Fast traffic
Partly Shared mobility	**Only shared mobility**
Unconnected	**Connected**
Traditional behavior	**Advanced behavior**
Low tech	**High Tech**

Sophie's future:

A few months ago Sophie connected besides her Facebook also her LinkedIn account to the mobility service provider Tesla. This because she is looking for a new job. When she is travelling she uses shared AVs in combination with a collective app provided by the government. The mobility service of Tesla is connected with a group of citizens who have the same interests. After the shared trip in an automatied four-seater, she can decide if she wants to travel with a fellow traveler again. As LinkedIn is also at connected to the app now, she may find a new job during her trip. Sometimes Sophie chooses to travel alone. She pays a bit more, but the advantage is that she can work in the car. She can for example prepare for a meeting. But usually she shares her trip and also avoids crowded areas in the city. This may take her a bit longer, but it is much cheaper and often it is enjoyable having some company. Sometimes she has to travel for work. Then she is allowed to choose a luxury AV, so she can have a meeting during her trip. Due to augmented reality it looks like everyone in the car is a hologram. After having been dropped off, the AV drives to the nearest passenger in order to pick him/her up, or if necessary it drives to a charging station, where it can also be cleaned. In the meantime Sophie takes an e-bike, which is specially reserved for her by the mobility service. After two more kilometers she arrives at her destination, which is on the other side of the road. It is possible to cross the road at any location, because all individual means of transportation in the mobility system are connected. An AV that is passing by stops automatically for Sophie on-her bike and she crosses the road . For pedestrians moving led lights in the road following vehicles show possibilities to cross the road. After work Sophie decides to run back home. On the streets there is a lot of space for pedestrians. Most of the time the AVs drive on small lanes that are well indicated by led lights. They do not park in the urban areas anymore so broad sidewalks and bike lanes are available to Sophie. Only some hubs tend to smaller sidewalks. After 6 kilometers she is too tired to run all the way back home. Luckily she is near a to an e-bike hub so that she can bike back to a hub only a few hundred meters from her house.

4. Microsimulation Traffic Model S-Paramics including scenarios

4.1 State-of-the art of microsimulation traffic model including automated vehicles

At the moment the MSTM S-Paramics is not yet to simulate scenarios with automated vehicles. For a long time, it has not been possible to use microscopic models in these kinds of simulation, but developments in modelling frameworks, data fusion, and an increase of computing power have led to the possibility of using microscopic activity-based models on a large scale (Rasouli and Timmermans 2013). At the moment the MSTM is used to analyse traffic flow and road network capacity when changing for example the road network and Travel Control Devices (TCD). The simulation has got different inputs concerning mobility production with specific parameters, which ensure the movement in MSTM. Besides these parameters, also other features of the vehicles, participating in the model, can be parameterised**,** such as reaction time, following distance, place on the road and the ability to avoid congestions. These parameters have been changed in extreme settings corresponding to the specific dimension which is associated with one of the scenarios. The microsimulation traffic model can work as a kind of framework and give directions to the possible parameters which have been used by conducting the scenarios. In paragraph 4.2 the advantages and disadvantages of using the MSTM are explained.

4.2 Advantages and disadvantages of MSTM

4.2.1 Advantages of microsimulation.

One of the advantages of microsimulation is, that it takes several aspects into account. These are: interaction between vehicles, dynamic route choice for each vehicle and effects of infrastructure, such as intersections and traffic lanes. Consequently, it is possible to get information about traffic queues, delays and route choices. Furthermore, there is the advantage of visibility, as vehicles can be shown on a screen (figure 7).

Microscopic models outperform aggregate models**,** because of a few reasons. First of all they capture particular behavioural mechanisms. Secondly, behavioural heterogeneity is possible and finally behavioural complexity is taken into account. Microscopic models show an improved sensitivity towards policy indicators, such as the amount of social exclusion, quality of life and time pressure (Rasouli and Timmermans 2013). These indicators are relevant, when modelling urban mobility in future scenarios with automated vehicles. Especially of importance, when modelling future mobility is the representation of the behaviour of individual vehicles on a road network. The vehicles observe the rules of the road and interact with other road users through a simple gap acceptance and car following rules. Also the human behavioural aspects present in the MSTM are important to reconsider as AVs will result in more robotic behavioural traffic patterns. Aggregate models do not possess such settings. The combined effect of modelling these individual components gives a detailed representation of traffic flow on a physical road network. Deterministic models as are used in macrosimulation, in which the output is fully decided by the parameter values and the original conditions, appear to work well for free flowing traffic, but have difficulty simulating the features regarding congested networks. As the road network has often reached the maximum capacity and at the same time urbanisation has increased more and more congestions occur. In these cases microsimulation is a logical choice.

Due to the differences between micro- and macrosimulation, microsimulation gives the characteristics of automated vehicles much more possibilities as far as the setting of the different parameters is concerned. Micro simulation comes up with more precise data. This is necessary to show reliable conclusions about the features that are determined by each scenario.

4.2.2 Disadvantages of microsimulation

A more general disadvantage could be using the MSTM in combination with scenario analyses**,** ~~This~~ because of the uncertain future of autonomous mobility. This means that the exact data that are used in the model (for example social economic data) are still uncertain. However, using them is necessary to run the model.

Another disadvantage of the MSTM is the limitation of the parameter settings. Some new settings do not function properly with respect to extreme changes in the behaviour of the vehicles. This implies that individual aspects of the human behaviour have still to be taken into account.

Furthermore, the vehicles are not yet connected and for this reason connectivity cannot be simulated (especially relevant for the collective side) and traffic signals cannot be deleted. For example, in the scenarios 3 and 4 anticipation of the AVs is of importance. When catting in lane and joining the traffic, connected vehicles will automatically keep more distance, so that waiting for a safe gap will not be necessary anymore. Unfortunately, this is not yet possible in S-Paramics. That is why queues still occur at e.g. intersections.

The same goes for traffic signals. When connectivity is not possible, these cannot be deleted. However, when automation is generally accepted, traffic signs should not be necessary anymore.

Finally, there is the disadvantage of the origin and destination matrix of S-Paramics. This is a constant matrix with no possibilities of being changed while simulating. In the future, it is necessary to have a more flexible model, as ride and car sharing will influence the matrix. Fortunately, it is possible to change the matrix manually. A small test is shown and explained in paragraph 6.4.

All the same, during this research an attempt was made to take the behaviour of automated vehicles into account as much as possible.

4.2 Automated vehicles simulated in the microsimulation traffic model S-Paramics

In this study for the first time automated vehicles will be simulated and modelled with in the MSTM S-Paramics. This is not only a new and important development with in MSTMs, the parameters of S-Paramics also offers boundaries for the scenarios that needs to be developed. It should be possible to backlink the features of the scenarios to the parameters of the MSTM. The scenarios are expected to give answers on parameters such as acceleration and deceleration, aggression and awareness, gap variations and rout choice differences. In table 6 the different effects of the parameters are explained and on which part of the MSTM the effect have its influence. The parameters need to be valued with the help of the scenarios later on it will be explained how. When the values of the parameters are determined and combined in the right way they will represent the mobility with the characteristics of the automated vehicles. For each scenario the values and the combination of the parameters need to be determined again.

Parameter group	***Parameters***	***Effect***	***Configuration settings***
Velocity dynamic	*Acceleration*	On vehicles in the whole network	Per vehicle type
	Deceleration	On vehicles in the whole network	Per vehicle type
	Speed limit	On speed limit	Per road category
Human behavriour	*Aggression*	On the behaviour of al vehicle types e.g. with an high aggressive setting. Vehicles take the decisions and brake at a later moment late and breaks late. This has side effects on several parameter.	Normal distribution on all the vehicle types in the network
	Awareness	On the behaviour of al vehicle types e.g. vehicles with a high awareness anticipate faster	Normal distribution on all the vehicle types in the network
Vehicle connectivity	*Minimum gap*	Distance between vehicles, also when standing still. Influence on the capacity e.g. a smaller gap results in more capacity.	All the vehicle types in the network
	Gap acceptance	On acceptance when a vehicle ~~have~~ has to do one of the following actions: Merging , crossing lanes/paths	On link level per roadcraft contrary to minimum gap and mean main? headway
	Visibility	On indicate indicating spotting one another	Per road category
	Mean headway	On distance between vehicles.	On network level
Route choice	*Cost factor*	On the route choice formula as resistance of time	Per road category
	Route choice formula	Standard formula: (1*T+0,25*D)*(feedback factor)	Per vehicle type
	Familiarity	Familiar vehicles use major and minor roads to avoid congestions unfamiliar vehicles take the most optimal route, which is calculated when the road network is empty. They take the cost factor and route choice formula into account.	Per vehicle type
	Perturbation	Percentage of dispersion of a vehicle, allowed to deviate from the most optimal route with respect to distance. With this parameter several routes can be chosen in order to get from the origin to the destination	Per vehicle type

Table 6 – Explanation of each parameter of the MSTM S-Paramics.

5. Revaluing parameters MSTM based on scenarios features

5.1 Choosing parameters and options

For simulation purposes vehicle parameters have to be adjusted and updated to adequately simulate the autonomous vehicles described in each of the scenarios. Therefore specific features for each scenario, with respect to mobility in combination with automated vehicles are determined. First of all the specific features for each scenarios have been noted. These features are about the mobility in combination with automated vehicles and are related to the scenarios. The features are: fast traffic vs slow traffic, less shared mobility vs only shared mobility, not connected vs all connected, traditional behavior vs advanced behavior. The features can be true or false and the answers per scenario are obtained by a brainstorm session with experts with knowledge about mobility in the urban environment.

The parameters provided by the MSTM S-Paramics which can be linked to these features are as follows: *Acceleration, Deceleration, Headway, Aggression, Awareness, Minimum gap, Gap acceptance, Mean headway, Speed limit, Cost factor, Route choice, Route choice, Route choice formula, Familiarity, Perturbation.* These parameters have their own units and are in the first place calibrated by the model providers of S-Paramics see tables 7,8,9 and 10 for the original values with their units. These original values form the reference for this research. One of the biggest differences between the normal use by employees of Sweco of the MSTM S-Paramics and the use of it in this research, is the fact that the parameters with respect to the vehicles and their behaviour have been recalibrated. For example with the normal use of S-Paramics, new infrastructure or signalling will be tested on road capacity and traffic flow. With the normal use of the model these values of the parameters that are going to be changed in this research are the fixed data in when simulating traffic. A problem has started in the urban environment, because the infrastructure is permanent and reached its maximum capacity. It is difficult to expand roads or building new road with in the existing road network. Therefor it is needed to find out what kind of influence the characteristics and the behaviour of the vehicles have on the road network capacity and traffic flow.

To do a solid research the parameters have to be tested separately and the effects on the Vehicle Hours (VH) and Vehicle Loss Hours (VLH) should be analysed. VH are of importance, because there is a fixed number of vehicles in the system and a fixed Origin and Destination Matrix (ODM). So when the analyses show more VH pertaining to the reference analysis in the same amount of time, the traffic flow and capacity is worsened and vice versa. An important fact while testing the parameter is to be alert about cohesion between the parameters. For example, there is a minimum gap an gap acceptance between the parameters. If you decrease the minimum gap between two vehicles because AVs are allowed to drive more close to each other, the gap acceptance has to be adjusted as well. If these two parameters are not correctly interacting with each other the vehicles in the simulation do not insert or cross a road in time, this will result in long queues of vehicles. After the tests have been executed the parameters should be combined in a logical way with corresponding values obtained with the help of the scenarios.

The values and combination of the parameters are established with the help of Sweco employees who have a lot of expertise with respect to the MSTM S-Paramics. First they empathise each of the scenarios to get a feeling how the mobility will behave in the future. This was done by reading storylines of future personalities. They are talking about a normal day in their life where they travel through a city. After reading this story the experts have been ask to come up with values of the S-Paramics parameters that are corresponding to the scenarios and fitting in the MSTM. Because of the cohesion and sensitivity of the parameters this have to be done really accurately.

5.2 Modelling autonomous vehicles in S-Paramics

5.2.1 Revaluing parameters.

Because of the many different parameters that can be changed it is first of all important to find out what the influence of each parameter is. This is done by testing the parameters in interacting combinations. These combinations are shown and the reasons of using new values will be shown and explained in paragraph 5.2.1. Afterwards they will be combinations as well as described per scenario. In order to properly do this research the interaction between the couples of parameters has to be checked. These couples have to be added one by one until all parameters are added together. This should be done for every scenario. In this research only the beginning of this process has been taken care of and will be analysed in chapter 6 and discussed in chapter 7.

5.2.1.1 Parameter group velocity dynamics

Parameter	**Reference scenario**	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
Acceleration	2.50 m/s^2	3.25 m/s^2	1.25 m/s^2	3.25 m/s^2	1.25 m/s^2
Deceleration	4.50 m/s^2	6.75 m/s^2	2.25 m/s^2	6.75 m/s^2	2.25 m/s^2
Speed limit	Original velocity km/h	Divide by 0.75	Multiply by 0,75	Divide by 0.75	Multiply by 0,75

Table 7 – Revaluation parameters acceleration, deceleration and speed limit.

Scenario 1 and 3

De first parameters that have been tested are acceleration and deceleration. These values have been chosen as the scenarios 1 and 3 are covered by the dimension efficiency. This means for both scenarios that fast traffic has got priority. Expectations are that for example fast acceleration from a standstill position contributes to the traffic flow. Think of platoon forming, where a whole chain of vehicles are accelerating fast like a train at the maximum speed limit (figure 13).

The speed limit on the roads will increase, because of the fact that velocity plays a big part in the dimension efficiency. On motorways the velocity is 120 km/h but will be 160 km/h and 100 will be 133. On urban roads the speed limit will change from 80 km/h to 106 km/h from 70 to 93, from 50 km/h to 66 km/h from 30 km/h to 40 km/h. In these scenarios the roads will be more distinctly separated from the foot- and cycle paths. The traffic of cars has priority and because of the autonomous vehicles, it is possible to increase the speed limit. On the individual side of scenario 1 the vehicles have the possibility to monitor what happens around them. In order to do so special equipment is used. On the collective side all are connected and get to know everything from one another. In this way safety can be guaranteed.

Scenario 2 and 4

In scenario 2 and 4 the values have been compared to the reference scenario this shows that de values have been decreased. Which means that in reality the AVs accelerate and decelerate more slowly. The reason is that experience plays a prominent role here. The viability of the city is important and pedestrians are very well protected, as a result of which the autonomous vehicles will have to be more careful with respect to their surroundings. But also in the vehicle comfort is important working and entertainment must be possible while passengers travel.

As a consequence the speed limit in these scenarios will be decreased. Often slower passing vehicles will be appreciated more by . For example sitting on a terrace and less and slower driving vehicles will contribute to a nicer experience will be better. From the passenger's point of view this will not be a problem, as they can make good use of their time while driving (Figure 10). The speed limit on the motorways will change as follows: from 120 km/h to 90 km/h, and from 100 to 75. On urban roads it will change from 80 km/h to 60 km/h, from 70 to 52,from 50 km/h to 37 km/h and from 30 km/h to 22 km/h.

Figure 10 – Increased value of time due to comfort and the ability to spend time freely on work or recreation.

5.2.1.2 Parameter group human behaviour

Parameter	**Reference scenario**	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
Aggression					
Awareness					

Table 8 – Revaluation of the parameters aggression and awareness.

Scenario 1 and 2

In the first two scenarios there will be no behavioural change in the parameters aggression and awareness. The reason is that these scenarios are on the individual side of the scheme Here passengers own their vehicles and it is up to them how to behave. There is no governmental regulation concerning aggression and awareness. Travellers can choose whether to take e.g. a fast or a scenic route. The vehicles are different in size and capacity, as a result of which the behaviour is different as well. They cooperate better together than not non- autonomous vehicles. The parameters aggression and awareness are normally distributed values with respect to the vehicles in the model. So most vehicles are placed in somewhere in the middle of the diagram with shows the degree of aggression and awareness. For example if a passenger is in a hurry he can command the AV to drive more aggressively. As the systems of automated vehicles are developed by different companies and as there are no governmental regulations with respect to these systems, the awareness of the vehicles can be different. The vehicles cooperate, but act according to their own self driving systems.

Scenario 3 and 4

In scenarios 3 and 4 there is no difference in behaviour between the vehicles. This is because all the AVs are directed by a central computer. This looks like a public transport system where no one owns a vehicle. The system makes the decisions all the same and cooperation between the vehicles is optimal. The system knows the exact location, speed and destination of all the vehicles. Everything is regulated by the government. For example, a traveller he can order an AV that can bring him to his destination.

When he is in a hurry he cannot change the rules. The only thing he can do is not sharing his ride, which is of course more expensive. The behaviour on the collective side of the scenario scheme is not normal distributed, the following changes in aggression and awareness have been made. The aggression of all vehicles is rated average this is done by flatten out the both extreme sides of the normal distribution. The awareness of all vehicles is optimal. this is done by shifting the normal distribution to the side where the awareness is the most extreme.

5.2.1.3 Parameter group vehicle connectivity

Parameter	**Reference scenario**	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
Minimum gap	4 m	2 m	2 m	1 m	1 m
Gap acceptance	4 m	2 m	2 m	1 m	1 m
Mean headway	3 m	1,5 m	1,5 m	0,5 m	0,5 m
Visibility	15 m	35 m	35 m	35 m	35 m

Table 9 – Revaluation of the parameters: minimum gap, gap acceptance, mean headway and visibility

Scenario 1 and 2

On the individual side of the scenario scheme the minimum gap, gap acceptance and mean headway have been slightly decreased. The vehicles are allowed to drive more closely behind each other, because of the safe self-driving systems. However, as the vehicles are not connected by one overall system, some distance should still be taken into account. Signs and traffic lights will not be necessary anymore, as self-driving systems avoid collisions and they decide upon priority at intersections. Queues will only occur occasionally. This is why it looks like the AVs are driving crisscross and unorganised in these two scenarios (Figure 11) The visibility is set on 35 meters instead of 15 meters. Self-driving vehicles have all kinds of systems with cameras and other technology that can see a lot more than the human eye. For example 35 meter in front of an intersection an AV already knows what obstacles will be there, due to lidar (using laser and light to measure the distance around a vehicle) radar technology (Figure 12).

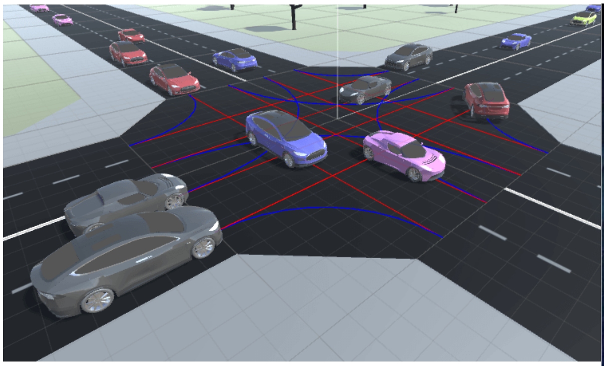


Figure 12. – Avs driving unorganised across a crossroad

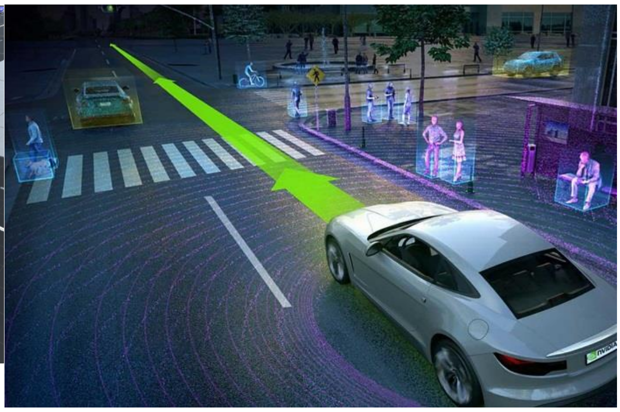


Figure 11 – Radar and lidar technology in operation at an intersection.

Scenario 3 and 4

In scenario 3 and 4 the AVs drive even closer behind each other there is a distance of 0.5 meter. This is possible, because in these scenarios the vehicles are not only autonomous but also connected to a system. This results in possibilities to form platoons (Figure 13). These platoons react like a kind of train, but can split up in different smaller modules. This is useful when passengers need to travel to specific places. The common vehicle nowadays has got five seats, but carries only an average of 1,5 passengers per trip, so small modules of a maximum of five or six people passengers are needed to fulfil all the needs. In these collective scenarios car sharing is the standard way of travelling and with drop on and off hubs changing to other mobility forms provides an easy way to travel through a city. With a minimum gap of one meter between the vehicles (at a standstill) a save way for pedestrians of crossing the road is guaranteed. A gap acceptance of 1 one meter is necessary to make sure all the vehicles can interact correctly. In the computer model S-Paramics a platoon form cannot be simulated, but with the correct settings a similar scenario will be modelled. The same goes for the parameter visibility with a maximum of 35 meters instead of 15 meters. This is the closest approach to a situation where all cars are connected.

Figure 13 – Platoon forming with small modules.

5.2.1.4 Parameter group route choice

Parameter	**Reference scenario**	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
Cost factor	Different per road type	All network the same	Main roads: lower. Sub roads: higher.	All network the same	Main roads: lower. Sub roads: higher.
Route choice formula	$T \times \frac{1}{4} D$	$T \times \frac{1}{4} D$	$\frac{1}{2} T \times \frac{1}{4} D$	$T \times \frac{1}{4} D$	$\frac{1}{2} T \times \frac{1}{4} D$
Familiarity	70%	100%	100%	100%	100%

Table 10 – Revaluation of the parameters: cost factor, route choice, route choice formula and familiarity.

These Three parameters are covered by sub-group “route choice”. They all give a reason why a vehicle should deviate from its original route. These routes are established by the most time efficient route choices during the free flow, based on the origin and destination matrix. During a traffic rush some vehicles are told to reroute influenced by these parameters. The dimensions efficiency and experience have the biggest impact. This results in the difference between scenarios one and three and two and four. For all the scenarios the parameter familiarity is increased from 70 to 100 percent. This means that all the automated vehicles are familiar with the road network because even nowadays almost everyone has a navigation system. So in the future, this system will be more and the self-driving systems will reroute more efficiently. Because the parameter familiarity is now equal in all scenarios the route choice will depend on the other two parameters in this micro-simulation traffic model, cost factor and route choice formula.

Modernist and intelligent city

In these two scenarios the dimension efficiency is central. This means that travel time reduction is most important. In order to achieve this the first parameter cost factor per type of road is equal on the whole road network in scenario 1 and 3. The cost factor represents the cost expressed in time. In the reference scenario the secondary road network has a higher cost factor than the main road. This results in rerouting vehicles to the main road network. But in scenario 1 and 3 when the cost factor is equal on main and secondary road network vehicles can reroute to the shortest route to come from their starting point to their destination. This leads to more spreading of traffic and reduction of travel time. The increase of efficiency will be achieved at the expense of walkability and cyclability in the city.

The second parameter of influence on the efficiency is the route choice formula $T \times D$. The unit T stands for time and the D for distance. In scenario 1 and 3 the unit T in this formula counts four times heavier than the unit D ($T \times 1/4\ D$). Because travel time loss in very important in these two scenarios.

Pleasurable and comfortable city

In scenario two and four the experience of the mobility is more important than the efficiency. So in contrast to the equal cost factor of main and secondary road type in scenario one and three in these scenarios there will be a distinct difference in cost factor between these two road types. Automated vehicles need to be repulsed from the secondary road network where walkability and cyclability has the priority. By giving a higher cost factor to the secondary road network the rerouting vehicles do not prefer to choose these roads. The same can be achieved by changing the route choice formula to $1/2\ T \times 1/4\ D$. In scenario 2 and 4 travel time is not that important because the value of time during the trip has increased.

5.2.1.5 Changing the origin and destination matrix

Parameter	**Reference scenario**	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
OG matrix	Current social economic data	5% more traffic	5% more traffic	5% less traffic	5% less traffic

Table 11 – More or less traffic per scenario.

The OG matrix is based on the social economic data obtained by Sweco experts. This matrix will probably change by the introduction of automated vehicles. Dependent of the dimension individual and collective less or more traffic will occur. In this research is chosen for changes 5% less or more traffic. This small number of 5% is chosen because it is interesting to see if it have already a big influence results of the analyses (Table 11).

Modernist and pleasurable city

In the modernist and pleasurable city the individual side of the dimension is dominant. This will probably result in more traffic. This is because with policy it will be more difficult to regulate mobility in the city because al inhabitants own their vehicles by themselves. In this situation they can use their vehicle more how they want to. Multiple reasons such as empty driving vehicles, induvial use of vehicles and more use of vehicles will lead to more traffic.

Intelligent and comfortable city

In the intelligent and comfortable city the dominant role of the dimension is the collective side. This will probably result in less traffic. Policy in this situation to reduce traffic is easier to full fill because the vehicles are not owned by their users. Different reasons will lead to less traffic such as: vehicle and ride sharing, multiple using possibilities of vehicles and better cooperation of vehicles.

5.3 Changing parameter values and the data analysis tool

This paragraph will be explain how to change the parameters and how to use the tools that analyse the data.

The most parameters can be changed in the S-Paramics programme itself by just changing the values. But some of the parameters are more difficult to change. For example the parameters minimum gap, gap acceptance, mean headway and visibility need to be changed in the link files of S-Paramics. The road network of S-Paramics is built with all sorts of different links. Each link has its own values. In appendix… an Excel sheet of these links and the formula to these can be found.

When the parameters are changed and the simulation can be carried out, one run stands for one morning rush from 06:00 till 10:00 in the morning. The part of the data that is interesting to analyse takes place from 07:00 till 09:00 in the morning. This is because the simulation has to start up and develop the mobility of the vehicles similar to a real situation. To analyse the data obtained with S-Paramics most of the time the Sweco data analysis toolbox has been used. This is a programme, which transforms the data of the MSTM to a textfile. This file can be used in Excel. One option of this tool is to obtain the following data: the amount of vehicles during one hour, the average travel time of all vehicles added up in one hour and the average travel distance of all vehicles added up per hour. With these data the Vehicle Hours (VH) can be calculated see formula A for the calculation. VH is the total amount of hours that all vehicles travel. In this system the hours from 07:00 till 09:00 in the morning have been taken into account. Also a confidence interval of 95% of these Vehicle Hours is calculated. The Vehicle hours are interesting, because there is a fixed origin and destination matrix in every simulation. Also the amount of time the simulation takes is the same. So, for example the only reason why the VHs can increase, is when it takes longer for the vehicles to travel from their starting point to their destination. This gives a rough estimation about a possible improvement or deterioration of the road capacity or traffic flow. Another data output can be Vehicle Loss Hours (VLH). The calculation can be found in formula B. With VLH**,** the hours that are lost or obtained with the new settings, can be determined. This is done by taking the average travel time of the first simulation hour as free flow of the vehicles to get from their starting point to their destination across the road network. After this, the average travel time of the hours of interest is subtracted from this first free flow hour and added up. VLH are of importance, because they show the amount of time that is lost or won. In the same way the absolute differences in VLH can be calculated. Why the relative VLH is used, is explained in the 'Discussion'.

These results are interesting but even more interesting is to know where these differences in VH and VLH come from. This can be examined with the data analysis tool of S-Paramics itself. This tool is capable of making layers of the road network per link and of giving several values. The most important for this research are: average speed, turn count links (amount of vehicles) and queues. What makes this tool interesting is the detailed comparison between the links of the road network. It is possible to make layers of the data of S-Paramics of the reference and make an overlay of one of the scenarios. Later on these layers can be deducted from each other and differences are shown. These differences can tell where in the road network road capacity or traffic flow is improved or not. For example you can see if the differences of average speed or amount of vehicles mainly occur at main ways or highways. Another example is if queues increase or decrease in front of roundabouts or intersections. With this data it is possible to deduce the influence of the parameters that are changed and later on the parameters can be combined more logical. In chapter 'Results' a start is made of this process.

Formula A:

$$\frac{1}{n}\sum_{i=1}^{n} V_i \mu(T_i) * \frac{1}{3600} = VH$$

Formula B:

$$\frac{1}{n}\sum_{i=1}^{n} \mu(T_{fi}) - \mu(T_i)V_i * 1/3600 = VLH$$

n = Amount of runs

V = Amount of vehicles

μTi = Average travel time of run i

μTf = Average travel time free flow of run i

VH = Vehicle Hours

VLH = Vehicle Loss Hours

6. Results

6.1 Reference/base scenario

The reference dataset is obtained by the analysing the base scenario. For this scenario the same settings will be used as in the original model provide be Sweco. These values can be found in the chapter above. The results are expressed in VH and VLH and are shown in table 12. An average of 5058 VH is calculated out of 10 runs in the between 7:00 and 9:00 in the morning with a confidence interval low of 95% results in 5016 VH and a confidence interval of 95% high results in 5099 with a difference of 83 VH. An amount of 182 VLH is calculated compared to the free flow hour this is shown in table 12.

Acceleration, decelerations and aggression, awareness and combination of these 4 parameters	**Reference**	**acc/dec modernist & intelligent city**	**acc/dec pleasurable & comfortable city**	**agg/awa intelligent & comfortable city**	**Combi intelligent city**	**Combi comfortable city**
VH average (07:00-09:00)	5058	5137	7062	4827	5210	5752
VH low (95% confidence interval, 07:00-09:00)	5016	5102	6783	4789	4933	5533
VH high(95% confidence interval, 07:00-09:00)	5099	5172	7340	4866	5487	5971
VLH average relative (07:00-09:00)	182	199	597	150	243	435
VLH average absolute (07:00-09:00)	182	79	2004	-230	152	694

Table 12 – Empiric results analysed with the MSTM in VH and VLH for the reference scenario, the parameters acceleration/deceleration and aggression/awareness and for the combinations between the two parameters.

6.2 What are the difference between the scenarios and the base scenario?

6.2.1 Acceleration and deceleration

For the parameter change in the acceleration and deceleration all scenarios results in more VH as shown in table 12 Where scenarios pleasurable and comfortable city with slower acceleration and deceleration significantly show more VH namely 7062 compared to the 5058 in the reference scenario. Also the difference in confidence interval of 95% between high and low is significantly higher namely 557 VH. The scenarios modernise and intelligent city performed better with 5237 VH this is only 79 VH more than in the base scenario but the acceleration and deceleration was increased in these scenarios in the discussion hypotheses will be formulated and interpreted for these results. The confidence interval show only a difference of 70 VH between the high and low interval. The same kind of changes are shown in the VLH the modernist and intelligent city show an almost same amount of 178 VLH. The pleasurable and comfortable a significant increase and the highest amount VLH namely 597. See table 12 for the above explained results.

6.2.2 Aggression and awareness

The parameters aggression and awareness in the modernist and pleasurable city have the same settings as the base scenario and therefore not shown in the table. The intelligent and comfortable city have new settings with these setting a decrease in VH and VLH is achieved. These parameter give

4789 VH is stead of the 5058 in the base scenario this is a decrease of 227 VH. The confidence interval of 95% has a lowest value of 4789 and a highest value of 4866 this results in only a difference of 77 VH. Also in the VLH is reached a decrease of 32 hours the difference between 182 VLH is the base scenario and 150 VLH in the intelligent and comfortable city. The results are shown in table 12 will be further interpreted in the discussion.

6.2.3 Combination of parameters.

In this combination for the intelligent city the higher acceleration and deceleration velocities are combined with the aggression and awareness similar to the advanced behaviour. This combination results in 152 more VH compared to be base scenario shown in table 12. When the comfortable city will be simulated the lower acceleration and decelerations velocities will be combined with the aggression and awareness similar to the advanced behaviour. In this scenario an increase of 219 VH is compared to the base scenario is shown. The confidence interval of 95% results in the intelligent city of a difference between low and high of 554 VH and in the comfortable city of a difference of 438 VH. The VLH are in both scenarios higher than in the base scenario for the intelligent city they results in an amount of 243 VLH and in the comfortable city even higher namely 435 VLH. Also these results are shown in table 12 and will be explained in the chapter 'Discussion'.

6.3 deviation from the average.

The plot shown in figure 15 shows the parameters averages with their deviation per run. The lines indicate the averages of each simulations. 10 dots for every simulation represent each run. This graph gives in overview of some notable findings. First of all the differences between the amount of VH is big. Especially with the parameter settings of acceleration and deceleration in the pleasurable and comfortable city. Also the combination of the comfortable city show a big amount of VH. The second remark is the deviation from the average especially from the a just explained high averages. The deviation is spread out see the marked dots indicated with "reeks" in the legend. In the discussion some hypothesis an interpretation will be given for these remarks.

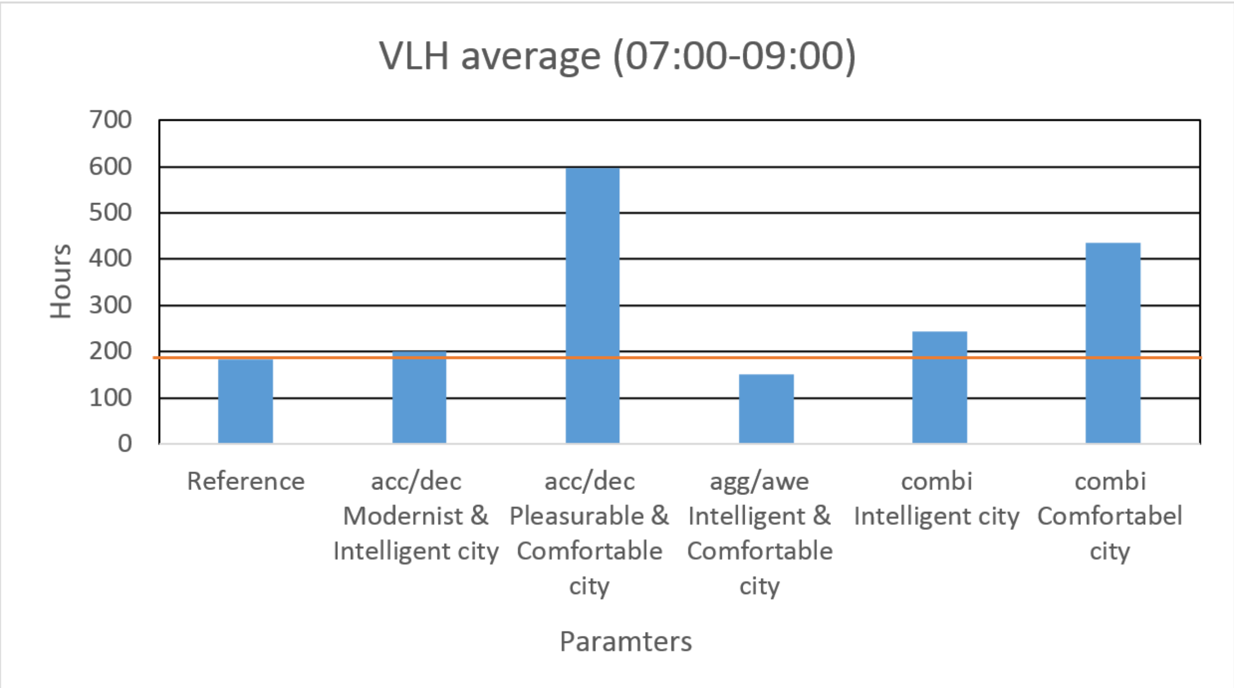


Figure 14 – A bar chart of the Vehicle Loss Hours for the reference scenario, the parameters acceleration/deceleration and aggression/awareness and for the combinations between the two parameters.

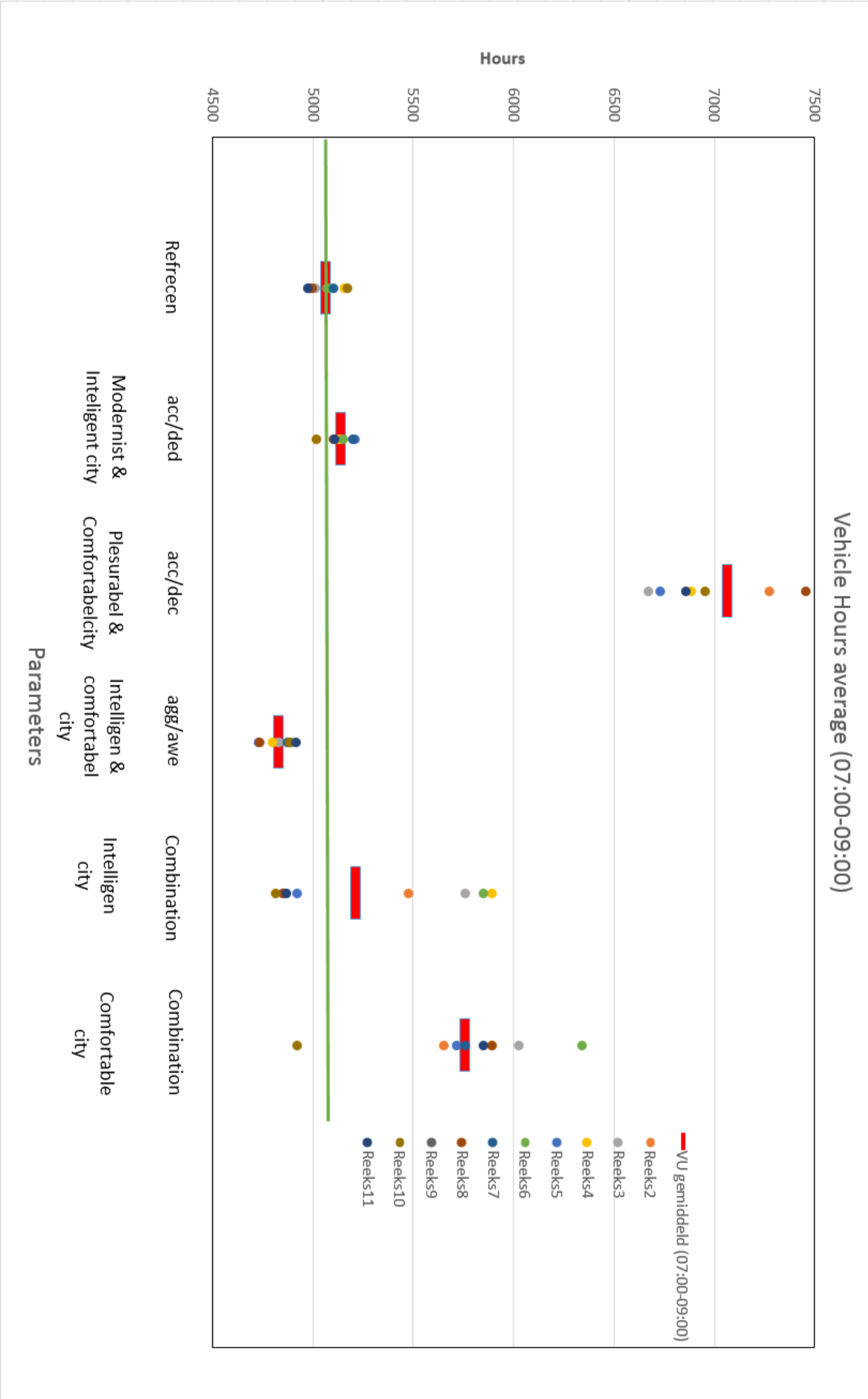


Figure 15 – The average Vehicle Hours indicated in red bars the dots named reeks are presenting the deviation around the mean this is an indication of the stability. The reference scenario, the parameters acceleration/deceleration and aggression/awareness and for the combinations between the two parameters are presented.

6.4 Origin Destination matrix

Changed origin-destination matrix	**Reference**	**5% more traffic**	**5% less traffic**
VH average (07:00-09:00)	5058	5860	4529
VH low (95% confidence interval, 07:00-09:00)	5016	5824	4498
VH high(95% confidence interval, 07:00-09:00)	5099	5896	4559
VLH average (07:00-09:00)	182	373	151

Table 13 – Results of the analyses with the MSTM showing 5% more and 5% less traffic.

5% more traffic

The results in table 13 and figure 16,17 show the differences in VH and VLH between 5% more and 5% less traffic compared to the reference scenario. With 5% more traffic the VH increase with about 15% 5058 against 5860 VH and the VLH even with 104% 182 against 373 VLH. The differences in confidence interval of 95% is 72 VH.

5% less traffic

With 5% less traffic the results show in table 13 figure 16,17 a different outcome the VH and VLH decrease compared to the reference scenario. The decrease in VH is about 10% namely 4529 against 5058 VH. The decrease in VLH is about 17% namely 183 against 151 VLH. The confidence interval of 95% show a difference of 61 VH.

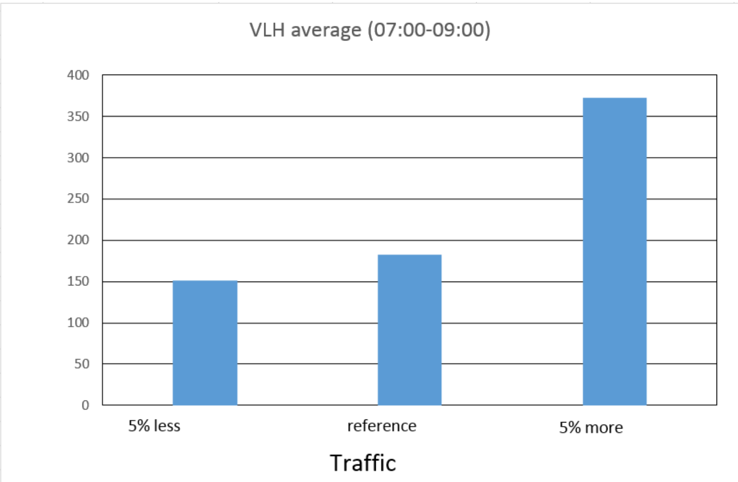
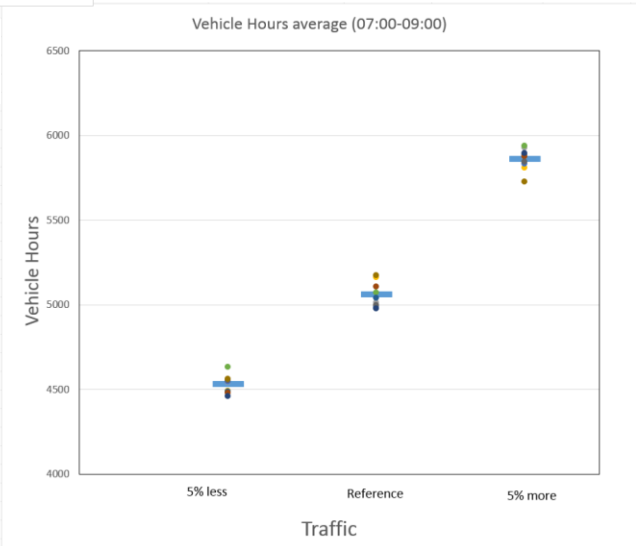


Figure 16 – Vehicle hours for 5% less, reference and 5% more traffic. the coloured dots are representing the deviation around the mean this is an indication for the stability of the setting.

Figure 17 – Vehicle loss hours for 5% less, reference and 5% more traffic.



7. Discussion

7.1 Interpretations and hypotheses of the S-Paramics results

7.1.1 The hypotheses

The scenarios have resulted in several hypotheses and these have been tested within the MSTM. Empiric results from the MSTM have been presented in VH and VLH regarding the parameter-groups acceleration/deceleration, aggression/awareness and combinations of these within the intelligent and comfortable city. The hypotheses have been divided into two groups: behavioural changes of vehicle features and a change in the origin and destination matrix.

Behavioural changes:

- In table 14 the hypotheses are shown for each parameter setting if the VH and VLH increase, decrease or remain the same concerning a specific scenario.

Hypotheses of VH and VLH per scenario	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
VH - Acc/dec	Decrease	Increase	Decrease	Increase
VH - Agr/awa	Remain the same	Remain the same	Decrease	Decrease
Combination acc/dec & agr/awa	-----	-----	Decrease	Increase

Table 14 – Hypotheses of VH and VLH presented in a table. Telling for each scenario if the VH and VLH will decrease, increase or remain the same per parameter setting.

Change in the origin and destination matrix:

- In table 15 the hypotheses are shown with respect to the results if more or less traffic result in more VH and VLH

Hypotheses of VH and VLH per scenario	**Modernist city**	**Pleasurable city**	**Intelligent city**	**Comfortable city**
5% less traffic	----	----	Decrease	Increase
5% more traffic	Increase	Increase	----	----

Table 15 – Hypotheses of VH and VLH presented in a table. Telling for each scenario if the VH and VLH will decrease, increase or remain the same when the traffic decrease or increase with 5%.

Besides these, there is another hypothesis that can probably be formulated. This involves interpretations of the empiric results and can be discussed in a negative and in a positive way:

- The MSTM shows a positive perspective on the mobility of the future by using AVs
  - Or
- The MSTM shows a negative perspective on the mobility of the future by using AVs

However, there are two comments to be noted when interpreting the results. First of all, the parameter settings show varying results. The outcome of one setting appears to be more stable than the other. This is shown in the deviation around the mean. If the deviation is considerable it is likely that the new parameter-setting does not operate well. According to the experts the reason of this deviation can be found in the lengths of queues, change of route choice, turning off the road, getting in lane and the random choice process within the model. Further investigation is required to find out the cause of less stable results. If there is hardly any deviation around the mean the results and therefore the traffic are more stable.

Secondly, it is possible to determine the VLH in two ways: relative and absolute. The relative VLH is calculated by comparing the average travel time of the first 30 minutes of the simulation as free flow of the vehicles to get from their starting point to their destination. After this the average travel time of the hours of interest is subtracted from this first free flow hour and the sum exists these differences are the VLH (see formula B). This has been done for every parameter setting individually. The absolute calculation is derived from taking the VH of the reference scenario and subtract the VH of the parameter that is of importance. The differences between these are the absolute VLH. This is shown in the table below. As the free flow for each new parameter sitting can be different with respect to each other the relative VLH is used.

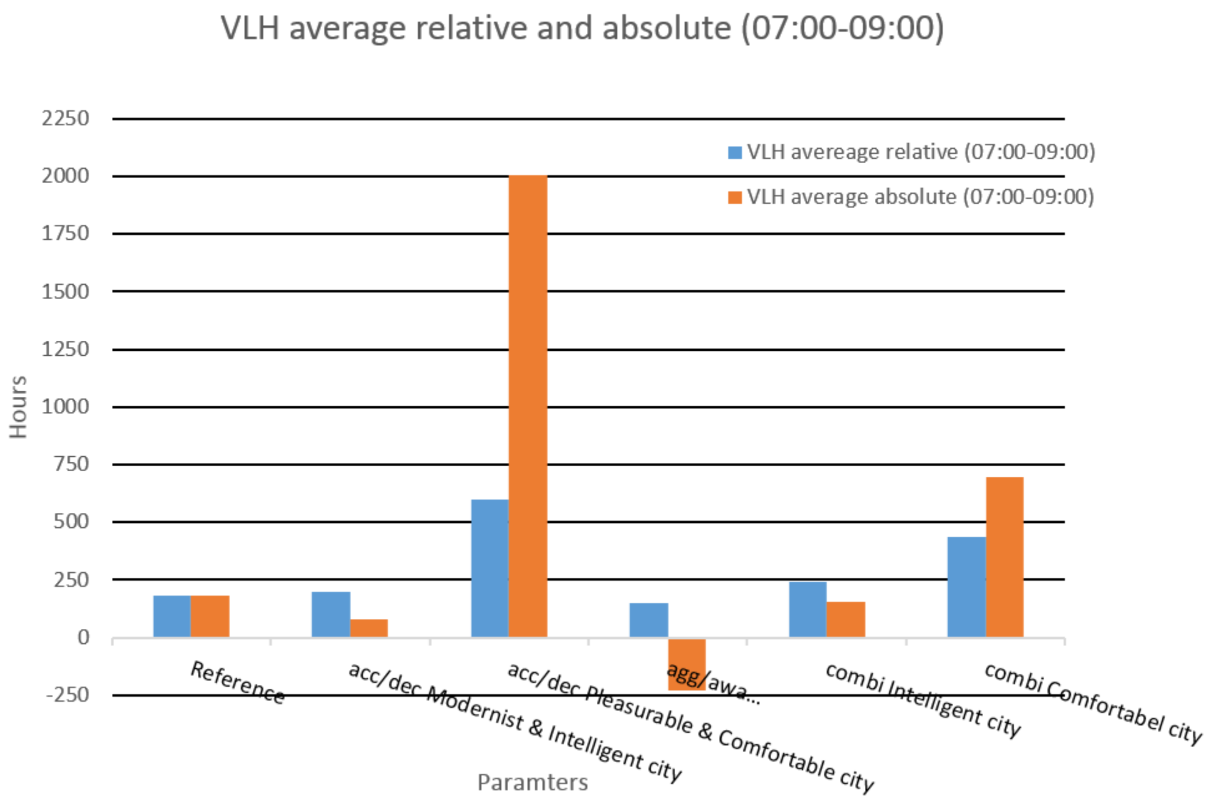


Figure 18 – Comparing the absolute (orange) and relative (blue) Vehicle loss hours for every parameter setting and some combinations between the parameters settings.

In order to better understand the discussion about the data and to prove the reliability of the hypotheses, figure… gives an explanation. It shows the total amount of seconds a vehicle is travelling on the road network with respect to the number of vehicles driving at the same moment and regarding all the parameter settings. Having analysed these data, it is noticeable that the amount of time a vehicle has to travel from its place of origin to its place of destination is about the same for each parameter setting. Looking into this with more detail, it has appeared that the time needed by a vehicle in the pleasurable and comfortable city is increased with respect to the parameter acceleration/deceleration. This is because the speed within the velocity dynamics has been decreased. Also the shape of the polynomial of the acceleration/deceleration parameter in the pleasurable and comfortable city is the most aberrant. In the interpretation below more explanations are given with respect to the instability of this parameter. Another point of attention. An important point of consideration is highlighted in figure 20 The parameter setting with respect to behaviour has one of the best fitting polynomial compared to the indicated data. This explains something about the stability of the results as well. This same parameter (aggression and awareness), the green polynomial in figure 19, starts and ended with less time the vehicles needed to travel from origin to destination. Later in the interpretations an explanation will be given why this is a promising result.

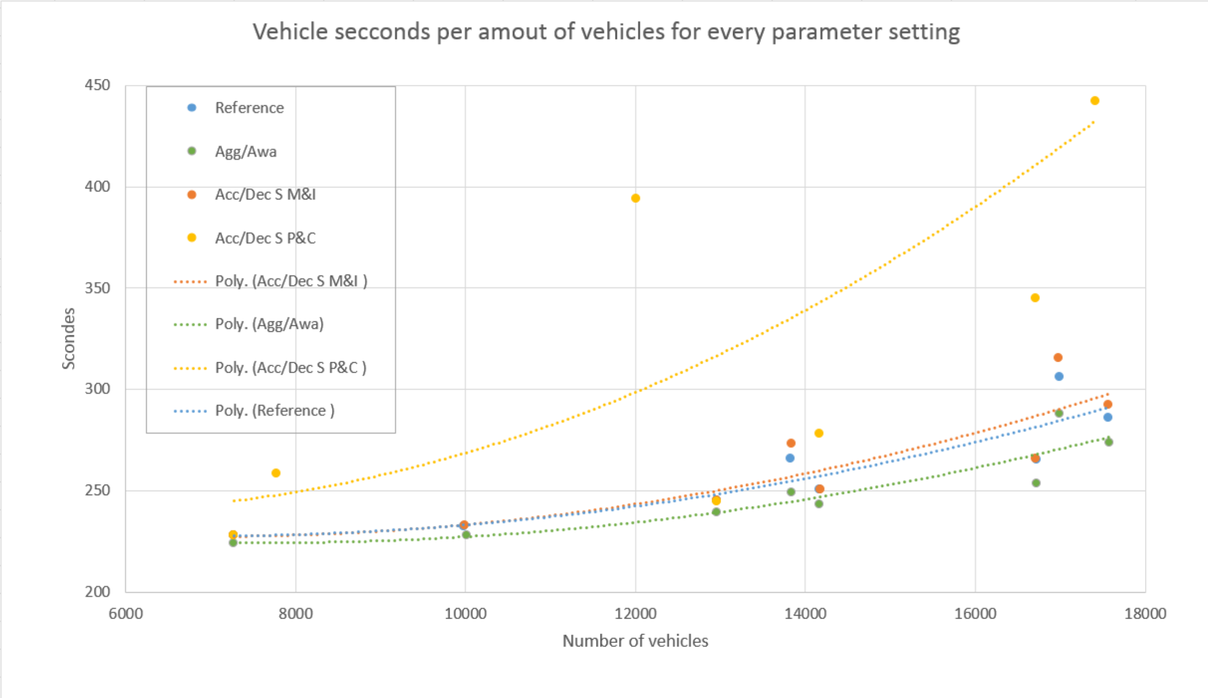


Figure 19 – Show the total amount of seconds a vehicle is travelling from its origin to destination with respect to the number of vehicles at the same moment and reading all the parameter settings.

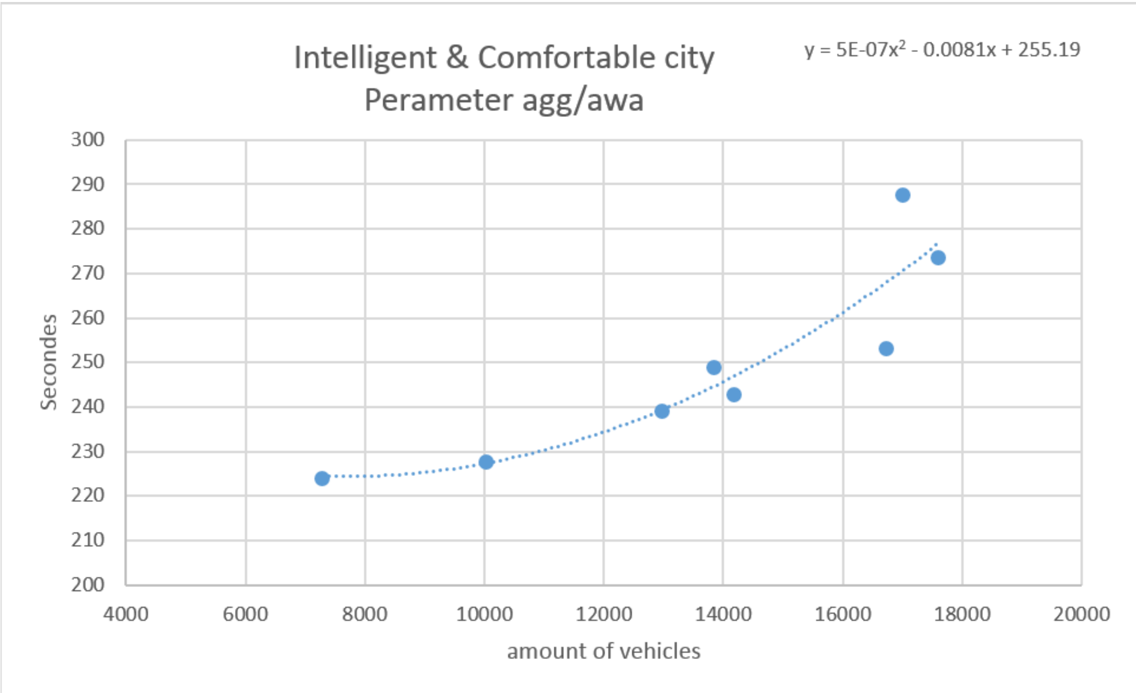


Figure 20 – Close up for the parameter setting Aggression/awareness of the total amount of seconds a vehicle is travelling from its origin to destination with respect to the number of vehicles at the same moment.

7.1.2 Interpretations

7.1.2.1 Acceleration and deceleration

Modernist and intelligent city

In the modernist and intelligent city the results of the acceleration and deceleration parameter are stable, because the deviation around the mean is small. The hypothesis of these results with respect the increase of velocity relating to acceleration and deceleration should lead to less VH and VLH. Unfortunately, this setting does not meet its expectation. A slight increase of VH and VLH arises which is not acceptable in these scenarios, as efficiency is an important factor. A possible explanation can be found in the fact that the cooperation between the vehicles is not optimal and in the fact that velocity changes all the time. This leads to problems in crossing the road and when joining the traffic. In order to cooperate in a better way, specific settings should be added. Another explanation can be found in the fact that a considerable amount of traffic in this model is largely based on situations on the motorways and not the subnetwork. A validation of the fact that this new parameter setting is not operating properly can be observed in the free flow calculation. Even when the vehicles are operating on the network in free flow modes the amount of VH should decrease compared to the free flow of the reference scenario. This is not the case at moment.

Pleasurable and comfortable city

The results of the pleasurable and comfortable city are less stable, because the deviation around the mean is large. The analyses of this parameter-setting results in the most VH and VLH. In these scenarios this is not such a big problem, because comfort is important as well. That is why it was hypothesized that the livability of road users would be increased, when the velocity with respect to acceleration and deceleration was decreased. Also the value of time is upgraded during a trip in a vehicle, so an increase of VH is not problematic. Only the amount of increased VH is a bit more than expected. Again the cooperation between the vehicles in this model could be blamed for this. It is important to find out where the longest traffic jams arise: on the main road network or on the sub road network. Also regarding this new parameter setting the vehicles do not operate properly. A validation can be found in the free flow calculation. When vehicles are operating on the network in free flow modes the amount of VH is increasing considerably compared to the free flow of the reference scenario.

7.1.2.2 Aggression and awareness.

Intelligent and comfortable city

For this parameter the changes are only made in the intelligent and comfortable city, as the behavioural human aspect**s** on the collective side of the dimension have almost all been eliminated. It is only in this parameter setting that the VH and VLH are decreased. The deviation around the mean is small as a consequence of which the result can be considered stable. The hypothesis tested by means of this result is the only one that is true concerning the parameter tested so far. The reason of this decrease is probably due to extreme awareness and almost zero aggression of the vehicles in the model, as has also been stated in the hypothesis. Changing the parameter awareness and aggression simulates better cooperation and anticipation of vehicles. For example when approaching intersections and other infrastructural situations. These analyses display the very first beginning of simulating connectivity between vehicles. However, it has already been discovered that just a small change results in a significant decrease in VH and VLH (figure 21 for the VLH) With respect to further research it might be interesting to investigate where exactly in the road network this decrease takes place. Besides this, it could be useful to see if the MSTM has the possibility to sufficiently simulate more connectivity, for example concerning vehicle platooning. The result of changing this parameter is promising, due to two reasons. First of all the result is stable and secondly the hypothesis has been proved to be true. Moreover, it seems that leaving out the parameters human aggressive and inattentive driving behaviour, which is possible by using AVs, is a positive development for the mobility in the future city.

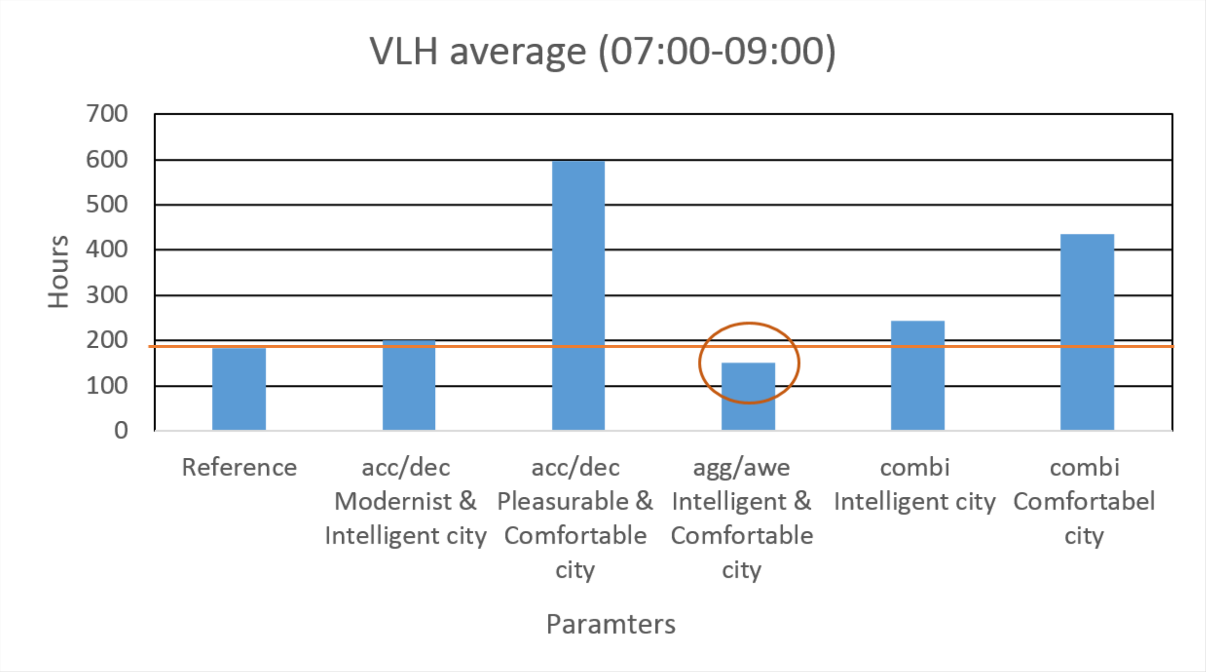


Figure 21 – A bar chart of the Vehicle Loss Hours for the reference scenario, the parameters acceleration/deceleration and aggression/awareness and for the combinations between the two parameters. Indicating the decrease of VLH of the parameter setting aggression/awareness.

7.1.2.3 Combination of parameters acceleration/deceleration and aggression/awareness

The intelligent city

The results in figure 15 show a combination of the acceleration/deceleration and aggression/awareness in an intelligent and comfortable city, in which efficiency and collectivity are emphasised. The deviation around the mean is considerable (Figure 15) and it is questionable how stable the results are. An increase in VH and VLH is not desirable in an efficient city. According to the hypothesis there should be an improvement. The combination between changes in the increase in velocity, less aggression and more awareness should result in less VH and VLH. However, the outcome shows a change for the worse compared to the situation when the parameters were tested individually. A probable explanation can be found in the fact that these parameters do not work well together. Identifying the exact place of the biggest increase of VH and VLH in the road network could be important for further research. Furthermore, it may be useful to see if and how the parameters could be combined in such a way that they work well together.

The comfortable city

The final combination that has been tested, is the one between acceleration/deceleration and aggression/awareness in the comfortable city. Here experience and collectivity are have been emphasised. Again the deviation around the mean is considerable, so the results are more unstable. The hypothesis that the VH and VLH should increase appears to be true but still a considerable amount of VH and VLH are added with respect to this scenario setting. Nevertheless, an improvement is shown compared to the acceleration and deceleration parameter, when tested individually. This is a promising development, as more awareness, less aggression and a decrease in changes in velocity result in less VH and VLH.

7.1.2.4 Less and more traffic

The hypothesis that VH and VLH will lead to a traffic increase of 5% and that the VH and VLH will lead to a traffic decrease of 5% have appeared to be correct. The percentage of VH and VLH in both traffic changes increase or decrease compared to the reference scenario. In the results is shown that 5% less traffic - leads to 10% less VH and 17% less VLH. It is promising that less traffic (5%) results in less VH (10%) and even less VLH (17%). Not very encouraging is the fact that 5% more traffic leads to an increase VH by 15% and VLH by 104% compared to the reference scenario. Comparing to the most promising new parameter settings of aggression and awareness, 5% less traffic is of big meaning by the decrease in VH see figure 16 and 17.

7.2 Pessimistic and optimistic viewpoints

The interpretation of VH and VLH can say something about two important criteria, i.e. traffic flow and road network capacity. The changes in the parameter setting of the features of the vehicles in the MSTM should be translated with respect to these two criteria. At this moment it is already possible to come up with a hypothesis concerning the positive or negative effect of AVs on the mobility of the future city. Translating VH and VLH into changes in traffic by using the two important criteria can be seen in a negative, pessimistic, but also in a positive, optimistic way. The explanation of these two hypotheses is as follows:

The MSTM shows a negative perspective on the mobility of the future by using AVs

The overall increase in VH and VLH cannot be compensated by the comfort automated vehicles can create. Besides this, the amount of rides will increase in the future because of empty driving vehicles and more use of vehicles, so this will have a negative impact on this result as well (about this aspect more in paragraph 7.5). After having tested the parameter settings, it is possible to conclude that AVs do not yet operate optimally regarding the mobility of the city. The settings of the features in the vehicles should be improved in such a way that these will eventually result in the desired scenarios. For example, by a better cooperation between the vehicles.

The MSTM shows a positive perspective on the mobility of the future by using AVs

Looking at the results especially with respect to the improvement achieved by the parameter 'aggression and awareness' a totally different point of view can be outlined. Just a small modification of the human vehicle features into more autonomous features, has already resulted in less VH and VLH. A homogenic feature of vehicles working together will result in mobility improvement. Using the right policy, shared rides will occur more often and a decrease in rides will be achieved. Zooming in on the most promising parameter (behaviour) the MSTM shows that AVs can be an improvement for the mobility in the future city. This parameter shows changes in the features of the vehicles and besides this a decrease in VH and VLH with respect to a constant OD matrix is seen. It is important, however, to make the right choices regarding policy during this transition in mobility, so that vehicles will contribute to an improvement of the livability of the cities.

7.3 Recommendations and challenges of microsimulation

The MSTM provides a lot of data, which are either stable or unstable. Most hypotheses are false or not reliable, towards autonomous vehicles in the future city, but some are true and promising. This has to refined by further investigation. Yet this research contributes significantly to the quantification of the mobility transition regarding autonomous vehicles. Qualitative and quantitative research come together in this approach when scenarios which focus on mobility from an urban point of view are used to revalue the parameters of the MSTM and provide empiric data. Several scientists recommend such an approach. The debate concerning this way of research is explained below. For example, there are some challenges that have to be tackled in order to use MSTM to provide more insights into the mobility of the future city with automated vehicles.

Scenarios are built to predict an unknown future. By using MSTM the scenarios can be made quantifiable. As microsimulation usually does not focus on the remote future, there are still a lot of uncertainties with respect to the model. However, according to Rasouli and Timmermans (2013) uncertainty in scenarios should not be met with a fatalistic attitude:

- "Rather, new concepts, tools and approaches should be developed to explicitly deal with the fundamentally probabilistic, conditional forecasts in policy assessments. (…) we should perform sensitivity analyses for critical parameter subspaces (…), identify trajectories that imply a resilient system, simulate internal system adjustment to external perturbations."

One of the most leading reviews of literary sources at this moment is the paper by Milakis (2017) about policy and society related implications of automated driving. Milakis has come up with some some recommendations as well:

- Empirical studies about first order implications of vehicle automation have got priority, as there are not yet enough empirical data about the use of AVs exists.
- Expanding the armoury of methods to capture behavioural aspects by using for example qualitative (focus groups, in-depth interviews) and quantitative methods (microsimulation) in order to tackle second and third-order implications.
- Looking into activity-based models to simulate several possibilities of changing the travel demand, vehicle ownership and environmental indicators.

In order to meet these recommendations the following information is important. With the help of Milakis' ripple scheme and in-depth interviews (qualitative) scenarios have been conducted for this research. Later on, these have been translated into the MSTM S-Paramics (quantitative).

Rasouli and Timmermans's recommendations have been taken into account as well. In spite of uncertainty, microsimulation has been used to focus on the remote future by using S-Paramics. Implementing this model in a different way it has appeared to be possible to focus on the remote future of: focusing on the remote future has appeared to be possible. By translating the features of the scenarios, including autonomous mobility, into behavioural aspects of the vehicles in the MSTM, S-Paramics has provided empirical results of first order and some second order implications. In order to use the traffic model in this way some challenges have to be tackled first.

1. Formulating the scenarios that have the potential to be quantified
2. Revaluing the parameters conform the scenario characteristics
3. Tackling obstacles of the model environment
4. Analysing the differences in the future mobility with autonomous vehicles.
5. Using microsimulation in order to get an insight into e.g. traffic flow and road network capacity changes concerning automated vehicles

In paragraph 7.4 the five challenges are discussed

7.4 Challenges of using the microsimulation traffic model to engage with AVs.

1. Formulating the scenarios that have the potential to be quantified

In the process of formulating scenarios the challenge is finding a balance between the creativity that is needed to build dynamic scenarios and the static features, which translate the scenarios into the parameters of the MSTM. One of the difficulties is keeping the diverse scenarios simplistic at the moment of combining them with the parameters. Some features of scenarios are difficult to simulate when using parameter that was originally meant for a different propose. This problem can be solved by using the parameters differently. An example is connectivity between vehicles. In order to simulate connectivity, the parameter visibility (it was used to human anticipation with respect to distance while driving), can be employed. When increasing the distance, vehicles spot one another sooner, so connectivity can be simulated. However, in view of the exact scenario features they still do not anticipate in the as future vehicles should do.

2. *Revaluing the parameters conform the scenario characteristics*

For this research experts helped to revalue the parameters conform the scenario characteristics and afterwards some tests were executed to come up with a realistic approach for the scenarios. This MSTM is actually built for the already existing mobility system. In this system every vehicle is operating individually by using a range of parameter**s** that have got some human behavioural aspects. Eliminating all these aspects in order to simulate autonomous mobility without human driving influences is not possible, simply because the parameter-values of S-Paramics cannot be changed sufficiently. All the same, an approximation of autonomous mobility is possible. When interpreting the results however, one should be attentive to the fact that the system is not yet perfect.

3. *Getting rid of the obstacles of the model environment*

*S*ome of the aspects mentioned above are part of challenge to getting rid of the obstacles of the model environment, but there are also other obstacles, which cannot be solved by revaluing the MSTM parameters. In the model landscape the infrastructure is based on the present situation with for example traffic control installations and other priority rules with respect to intersections. The second ripple of the ripple scheme shows scenarios in which these aspects will have to change in some future scenarios. The 'infrastructure' and 'location choice and land use implications' are affected by AVs. This will result in changes of mobility. At the moment, these changes are disregarded in the MSTM. Also the social economic dataset is based on the present situation. This dataset provides the origin and destination matrix. In the first ripple of the ripple scheme it is shown that changes will occur in 'travel choices' and 'traffic implications' and in the second ripple 'vehicle implications' are explained. All this will result in changes in the social economic dataset and in the origin and destination matrix. At the moment these changes of social economic aspects are not yet included in the MSTM.

4. *Analysing the differences in the future mobility with autonomous vehicles*

The data obtained from the simulations, expressed in VH and VLH, give some insight into the effect AVs will have on the road capacity and traffic flow. Not only is it important to analyse the difference in road capacity and traffic flow, but also to find out where changes in capacity and circulation of traffic arise on the road network. This can also be analysed by using the S-Paramics tool. This tool puts several scenarios on top of each other. The difference in between shows the traffic situation in which advantages and disadvantages of AV occur. However, as a result of the transition in mobility there are also new insights that should be analysed, such as the livability of the future city. These are shown in the last ripple of the ripple scheme and are called 'societal implications'. Nowadays the MSTM is still used to optimise the infrastructure in order to extend the circulation of traffic and capacity. In the future it will be important to create more design space by changing the properties of the AV. It will be a challenge to use the MSTM in such a way that 'societal implications' can be quantified and interpreted. The availability of the amount of design space might be a good criterion.

5. *Using microsimulation in order to get an insight into e.g. traffic flow and changes in the road network capacity concerning automated vehicles*

The challenge how to use microsimulation in order to get an insight into the effect on traffic concerning automated vehicles is partly discussed in challenge four. VH and VLH can give some information about road capacity and traffic flow, but this should be specified a bit more. Especially with respect to the MSTM every single vehicle is modelled and can be followed on the road network every second. This provides a lot of data, which can be analysed. It is possible to look at each traffic situation with respect to the effect a specific parameter or parameter-setting has got on each traffic situation (for example roundabout and intersection). With the help very detail MSTM data it might be concluded that different settings have got varying effects on specific traffic situations. As a result the parameter can be exactly set according to each feature of every scenario. The parameters have not yet all been tested in this research. In paragraph 7.3 a number of hypotheses and interpretations concerning this fifth challenge are explained. These are concluded from the changes in VH and VLH.

8. Conclusion

This research tries to answer the question with respect to the insights, which can be provided by a microsimulation traffic model as far as the impact of autonomous vehicles on urban mobility in the future is concerned. Especially the behaviour of the vehicles has been adjusted in order to simulate automated vehicles. The model provides empiric results in VH and VLH, which can be translated into two criteria: road network changes and traffic flow changes. During the research, several hypotheses have been set up concerning the changes in VH and VLH, caused by behavioural adjustments of the vehicles. A complete answer to this question, however, cannot yet be given here. The importance of this research is shown in the translation of the scenarios into the MSTM. Several scientists (Rasouli & Timmermans 2013, Milakis et all. 2017) recommend and use qualitative and quantitative research at the same time to gather empiric data about future mobility with automated vehicles. In spite of the fact that the MSTM should be improved somewhat, this model has already turned out to be important regarding quantification. It has provided useful data and has already given some insights into the urban mobility of the future by changing the behaviour of the vehicles.

One of the remarks about the scenarios, which have been established to revaluate the parameters of the MSTM, is that they are developed with respect to the mobility in the city as a starting point and not with respect to the technology of the automated vehicles. For every scenario the behaviour of the vehicles is adjusted in such a way that they are an improvement regarding the mobility in general. The reason of applying this approach is the fact that back casting from the desired scenarios helps to contributing regarding the advantages of automated vehicles.

First of all, an increase in the VH and VLH of the most tested parameters is noticeable. This does not mean that the outcome is not promising regarding automated vehicles. When paying attention to the results in more detail, it can be observed that there are some promising aspects. In order to show these, the conclusions are categorised into two parameter groups, which have been analysed: velocity dynamics and human behaviour. These are explained per scenario.

Parameters about velocity dynamics

In general the VH and VLH are increased for every parameter that is tested in this parameter group concerning acceleration and deceleration.

Modernist city and Intelligent city

In these two scenarios an increase in VH and VLH is still shown which does not come up to predictions decrypt in the hypotheses. That is why the behaviour autonomous vehicles has to be adjusted in the parameter settings in order to reach the intensions of these scenarios.

Pleasurable city and Comfortable city

In the scenarios Pleasurable and Comfortable city the results of an increase of VH and VLH are not necessarily negative. Within the dimension of experience, Vehicle Loss Hours are not by definition lost hours, because the value of time is upgraded while using the AV. The livability in the city is improved as well, because of slower acceleration and deceleration. Relatively, seen the amount of added VH and VLH is too extensive. So these scenarios regarding the new parameter settings do not meet hypotheses.

Behavioural parameters

The parameters aggression and awareness provide promising results, because these show a decrease in VH and VLH.

Intelligent city and Comfortable city

In scenarios of the Intelligent and Comfortable cities human behavioural aspects of the vehicles have been eliminated, which has resulted in a decrease of VH and VLH, according to the hypotheses. This development shows that automated vehicles have favourable consequences on the mobility in the future city. Human features (more aggression and less awareness) are the most important causes of congestions. A positive effect on the mobility can be reached by leaving out these human features. Consequently, it can be concluded that autonomous vehicles have the potential to improve the mobility in urban areas by changing the behaviour.

In accordance with the results, analyses show positive effects on the mobility by eliminating human features (causing aggression and less awareness, while driving). That is why it can be concluded that AVs have got a positive effect on the future city according to the data obtained by the MSTM.

After having finished the complete research, it could be concluded that modelling autonomous vehicles in urban areas gives an insight into the mobility transition. By using microsimulation it is possible to adjust the behaviour and the features of the vehicles and to leave the infrastructure unchanged. A positive change towards road network capacity and traffic flow can be reached. This offers a lot of perspectives, in spite of the fact that the infrastructure of the urban area cannot usually be extended. The focus should rather be on creating new 'design space'. As a consequence the livability of the city will be improved.

The scenarios which have been developed for this research, have provided some transition paths. These can be used by policymakers regarding their city and the influence of the AVs. The conclusion on the basis of the results only shows the beginning of scenario-modelling. In the long run all advantages and disadvantages of changing vehicle behaviour will be analysed with respect to the traffic flow and road capacity. This can be interpreted in such a way that the mobility in each city can be transformed in order to satisfy the policymakers. Prior to coming up with more insights and giving policy advises more research is needed. That is why a number of recommendations are given in chapter 9. These are subdivided with respect to the following categories: traffic modellers, policymakers and researchers.

9. Recommendations

Already in the beginning of this research it appeared that answering the main question would take more than just this analysis, as working with a traffic model in combination with autonomous vehicles is a new development in this field. Designing scenarios itself has not raised extra questions. These have been well-founded by using literature and interviews, as a result of which most situations in the city of the future have been covered. However, modelling these scenarios by using autonomous vehicles is very innovative. That is why a lot of new questions have arisen that have remained unanswered so far. These have been divided into three groups: one with respect to traffic modellers, one with respect to policymakers and one with respect to scientists.

9.1 With respect to scientists

What changes in generating rides takes place OD matrix

One of the most important steps to be taken in a further research is to find out what changes in generating rides will take place. It is recommended to get to know in what way the social economic data will change in each situation.

The need of traffic control devices

It could be interesting to find out, whether traffic control devices can be removed and what the effect will be on vehicles on for example intersections. The traffic flow and the capacity of the intersection will probably change. This has consequences for pedestrians and cyclists, when crossing the road.

Testing hypotheses with respect to the differences in VU and VLH

The data that have been concluded from the analyses are valuable and useful to get a better insight into the effect of autonomous vehicles in the city of the future. It should be possible to get more data analyses than have been achieved up to now. At this moment only changes in VU and VLH for each parameter setting have been shown. Furthermore, there are a number of hypotheses concerning the possible cause of these changes. The S-Paramics Toolbox can be of value in this matter. In paragraph 5.3 this is explained in more detail.

Creating new design space

Because of the advantage of adapting the behaviour of cars by using microsimulation the road network can remain unchanged. Yet the capacity and the traffic flow can be improved. The model shows where these improvements can take place. In the future new design space could be created here.

9.2 With respect to traffic modellers

S-Paramics without traffic control devices

Regarding the mobility in the city of the future, traffic control devices will be used less than before or not at all, because vehicles can communicate with each other or can be controlled by a central system. Traffic modellers should find out if it is possible to remove traffic control devices from the S-paramics road network.

Tackling limitations of S-Paramics

In the paragraph 'Limitations of S-Paramics' a number of limitations are mentioned that could be of interest to qualify for further research. Especially the limitation 'modelling connectivity between vehicles'. It is highly probable that vehicles in the future will be in connected with one another and they may even be controlled by a central system. At this moment the vehicles within the model still operate on a rather individual basis. A possibility to simulate cooperation could be quite some contribution to the model. Especially when platooning in the traffic system could be modelled.

How can parameters that have been changed and lead to unstable results be more stabilised

At this moment two parameters have been tested: the parameter with respect to the velocity of acceleration and deceleration of the vehicles and the parameter regarding the simulation of the behaviour of the cars. It will certainly be of added value to test all the parameters individually as well as in combination with other parameters. On the basis of the scenarios and the suggestions concerning the parameter settings, which have already been tested in this research, it will be possible to come up with reliable results.

Besides this, it is important to keep an eye on the stability of the results. Some parameters show a considerable deviation of VH and VLH around the mean. This gives an idea about the (in)stability of the road network in combination with a specific parameter setting. Finding out what the origin of this (in)stability is and what can be done about it may be of considerable influence with reference to obtaining more stable results.

9.3 With respect to policymakers

What is the right policy to aim for a specific scenario?

The behaviour of vehicles in the city of the future will play a significant part according to the results of the research. Testing more parameters after the hypotheses have been analysed will be of added value in order to write recommendations for each scenario and to come up with the optimum settings for the behaviour of the vehicles.

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