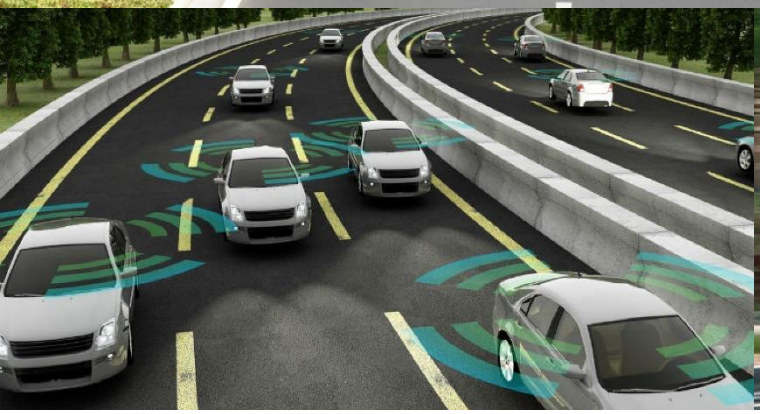
City planning and autonomous cars

How the use of space in cities will change as a result of autonomous cars



Bachelor thesis

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Spatial Planning & Design

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Abstract

In this research the extent of how autonomous cars will change the use of space in cities is being researched. How can we steer this evolution of the autonomous car to the most desirable outcome of future cities?

The central question of the research is: ''How will autonomous cars change the use of space in inner cities?'' This question will be answered through qualitative research methods. Interviews with semi-structured questions have been done with experts in the area.

There are five levels of autonomy, this research is mainly focused on the fifth level of autonomy, which means that cars are completely self-driving. There are two main scenarios of full autonomous driving. One in which autonomous cars are still privately owned and one in which cars are shared.

The emerge of the autonomous cars will have big spatial consequences for cities. However it is not instantly clear what will happen. It is probable that inner cities will only suffer more congestion, it is extremely hard to solve this. However cities will also experience positive results due to autonomous cars. Fewer parking space is needed in cities. These vacated spaces can be used for greenery, water, but also for housing.

Spatial planners should try steer the evolution of the autonomous vehicles towards the shared cars scenario instead of the privately owned autonomous vehicle scenario. This to steer the evolution of the autonomous vehicle to the most desirable outcome with minimal congestion and maximum liveability in cities. Governments should encouraging shared cars, for example by policy and campaigns.

Colophon

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Chapter 1: Introduction

1.1 Background

Currently, the car is very much embedded in our society. As a result of the rise of the car, people began to live further away from their work and relatives. Many urban areas were (re)designed for cars. Some places are not even accessible without a car. It is clear that the 'system of automobility' has been very influential in the way we live and the way cities are planned. However, a new 'system of automobility' might be ahead, the post-car society (Urry, 2004). In this new system, the use of the car will not decrease, there will be a shift in the car as vehicle itself. Cars will become (more) autonomous. The rise of the autonomous car will change the whole 'system of automobility' and will therefore have a massive impact on cities and society (Fraedrich et al., 2015).

It is thus expected that the rise of autonomous vehicles will result in a change in how we use space in inner cities. There are different scenarios of how the future of autonomous cars will look like. Will autonomous cars be privately owned like cars today, or will car sharing be the future? This is one of those crucial questions. These different scenarios can give completely different answers to the question of how autonomous cars will change the use of space in inner cities, this is therefore very interesting to research. This research is mainly focused on the inner city. The reason for this is the fact that the inner city is the most complex and unpredictable location in a city, with a lot of different modes of transport. Because of this complexity it is very interesting to research the consequences of autonomous driving in the inner city. In comparison, rural areas are much more predictable. The future in these locations is already a lot more clear than the inner city. Therefore it is more interesting to research the consequences in cities.

1.2 Research problem

The aim of this research is to research how autonomous cars will change the use of space in inner cities. The spatial implications of autonomous vehicles will be researched. It is also useful to know how we can steer this evolution of the autonomous vehicles to the ideal future scenario. It is necessary to gain an understanding of the requirements and conditions to achieve the ideal outcome. To be able to do this, it is necessary to gain an understanding in the different future scenarios of autonomous driving. Futures studies are part of this research.

The central question of the research is: *''How will autonomous cars change the use of space in inner cities?''*

The sub questions will be:

- What is autonomous driving?
- What are the different scenarios of autonomous driving?
- How will autonomous driving change the use of space in inner cities?
- How can spatial planners and governments steer the evolution of the autonomous vehicle towards the most desired outcome with human-centred cities?

1.2 Hypothesis

The future of autonomous cars is uncertain. In rural areas and highways, the introduction of autonomous cars is expected to decrease congestion. However, according to Chase (2014), the future of autonomous cars in cities is much more unpredictable. A positive spatial impact for cities is expected in a scenario with car sharing. In this scenario, much more space will be available in cities. The liveability is expected to increase. However, in a future of autonomous cars without car sharing, it is expected that congestion will only increase, the liveability in cities will decrease.

1.3 Structure of the thesis

This research consists of five chapters. After this chapter (Introduction), in the second chapter the theoretical framework will be discussed. This chapter includes the concepts of the different scenarios. In the third chapter, the methodology of this research will be discussed, this chapter will explain how data is collected and will explain the choice of data collection. Chapter three also includes a section about ethics. In the fourth chapter the results of this research will be presented. In the fifth and last chapter, the conclusions will be made. After the conclusion the references, which are used for this research, will be shown.

Chapter 2: Theoretical Framework

2.1 Introduction to autonomous driving

In the article ''The 'system' of Automobility'' written by Urry (2004), the system of automobility is being examined. According to the article, in the current system automobility is a source of freedom and flexibility. But, automobility has a lot of negative aspects as well. Automobility can also be seen in a constraining way, it produces a desire for flexibility, which only the car can satisfy. Many urban areas are designed just for automobility, without taking into account any other transport modes. The article states that a new automobility system can arise. The post-car system.

The article ''Transition pathways to fully automated driving and its implications for the sociotechnical system of automobility'' by Fraedrich et al. (2015) is about autonomous cars and the shift that this development will cause in the system of automobility. Just like the article of Urry (2004), the article of Fraedrich et al. (2015) does clarify the concept of the ''system of automobility''. The car is very much embedded in our society on a lot of different facets. The car is dominant regarding other transportation modes. Fraedrich et al. (2015) discusses the possibility that, in a change in the system of automobility, the use of the car will not decrease, but that there will be a shift in the car as vehicle itself. Cars will become (more) autonomous, which can also change the system of automobility.

The article *''Autonomous Driving, the Built Environment and Policy Implications''* written by Fraedrich et al. (2019) states that mobility and transport are closely connected with urban areas. The form of a city decides the mode of transport used in that city and vice-versa. For example compact cities with high density and mixed use do have an efficient public transport system. This kind of city design will also encourage people to bike and walk. Commuting can become more attractive due to the rise of autonomous cars. It is possible that people will move from the city centre to the edges of the city. So the rise of the autonomous car may result in a higher suburbanisation. It might even be possible that the relationship between mobility and urban land use will completely change (Fraedrich et al., 2019).

According to the article, home parking will not change much when cars will remain privately owned. In inner cities, cars will drop passengers and park itself in collective garages, this will save space. Suburbs further from the city centre will grow, as people are more willing to travel longer, due to the fact that autonomous driving makes driving more attractive. A higher vehicle density is possible with autonomous vehicles. Therefore, the number of traffic lanes and the lane width could be reduced. This extra space can then be used to encourage walking or cycling for example. Also, the segregation of different transport modes will be necessary to maximise the benefits of the autonomous vehicle.

History

In recent years, the development of the autonomous car has gone rapidly. Whereas the idea of a self-driving car was ten years ago still something for the far future, it is now slowly becoming reality. Already since the 1950s, the idea of self-driving cars has emerged. For example, ideas about smart highways, in which a road system would make cars self-driving on highways. This can be seen in figure 1.

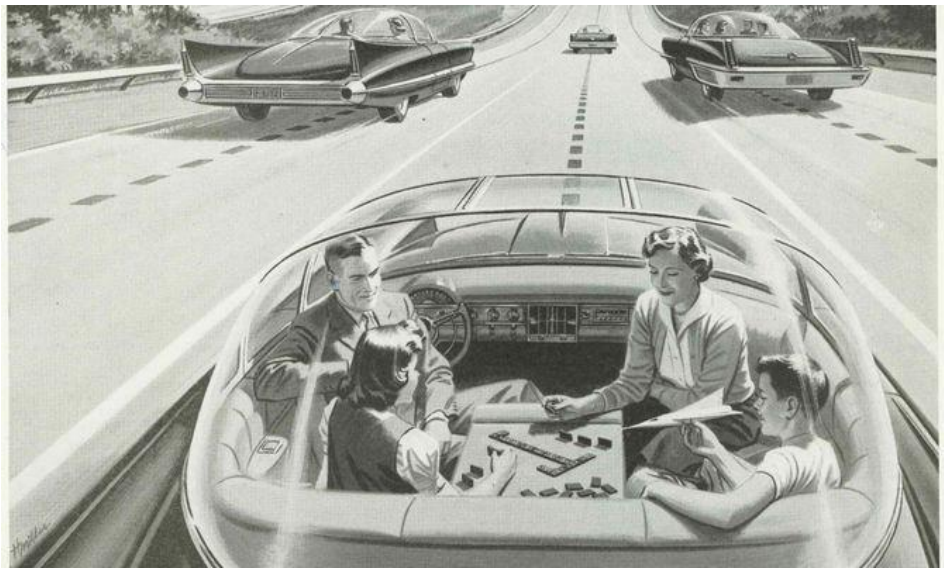

Figure 1: An advertisement from the 1950s about a driverless future (America's Electric Light and Power Companies, 1957)

In the 1960s, when artificial intelligence on computers started to develop, the dream of smart and autonomous cars slowly started. In the 1980s, the technologies improved, technologies such as the cruise control were introduced. In the 2000s, the research in autonomous cars continued, companies such as Google developed it even further (Weber, 2014).

Today, a lot of companies are working on the development of the autonomous car. Not only car manufactures are working on the development of the autonomous car. Also tech companies are working on it, sometimes with an alliance with car manufactures (Hussain & Zeadally, 2019).

Definitions

Automated cars are not the same as autonomous cars. Regarding automated cars, you can think of devices such as (adaptive) cruise control, the car still needs some form of human control. Autonomous cars, on the other hand, are able to drive completely independent, without the need for human control. Another semi-separate concept is the concept of connected driving. This means that vehicles are able to communicate to each other. This can be very useful for autonomous vehicles. Cars will not only be communicating to each other, but will also react on other vehicles (Hussain & Zeadally, 2019).

It is important to be clear about the definition of autonomous driving. An internationally accepted classification is the levels of automation classification system developed by the Society of Automotive Engineers (SAE) (2018). This system distinguishes the rate of automation of cars. According to the system there are 6 levels of automation (Bashir & Chatterjee 2018).

Level 0 (No Automation): In this level there is no automation. The driver controls the car completely by his own, without any system interventions.

Level 1 (Driver Assistance): In level 1 the driver is still fully driving the car by his own. However, there are some technical advantages that may help assist the driver. These are devices such as adaptive cruise control.

Level 2 (Partial Automation): In this level, in some situations the system takes over the task of driving, but the driver is still always in full control of the vehicle. In this level, cars can stay in their own lane and slow down on their own. Also autonomous parking is a characteristic of this level.

Level 3 (Conditional Automation): In the third level, cars can actually drive by themselves in a mapped environment. However, the driver needs to pay attention to be able to take over the control in complex situations. So drivers still need to monitor the driving of the car.

Level 4 (High Automation): In level 4, the car can drive in basically every situation by itself. There is no need for human intervention in the cars driving system anymore. However, the car can still be driven manually.

Level 5 (Full Automation): In the level 5 stage, cars are driving around completely autonomous. Cars are independently driving around. People cannot drive the car anymore.

In level 0, 1 and 2, the human driver monitors the environment, in these levels (excluding level 0) you can call the car automated. In level 3, 4 and 5, the system monitors the environment. In these levels, cars do have some form of autonomy. Then you can call the cars autonomous, see figure 2 for a clarification (Bashir & Chatterjee, 2018).

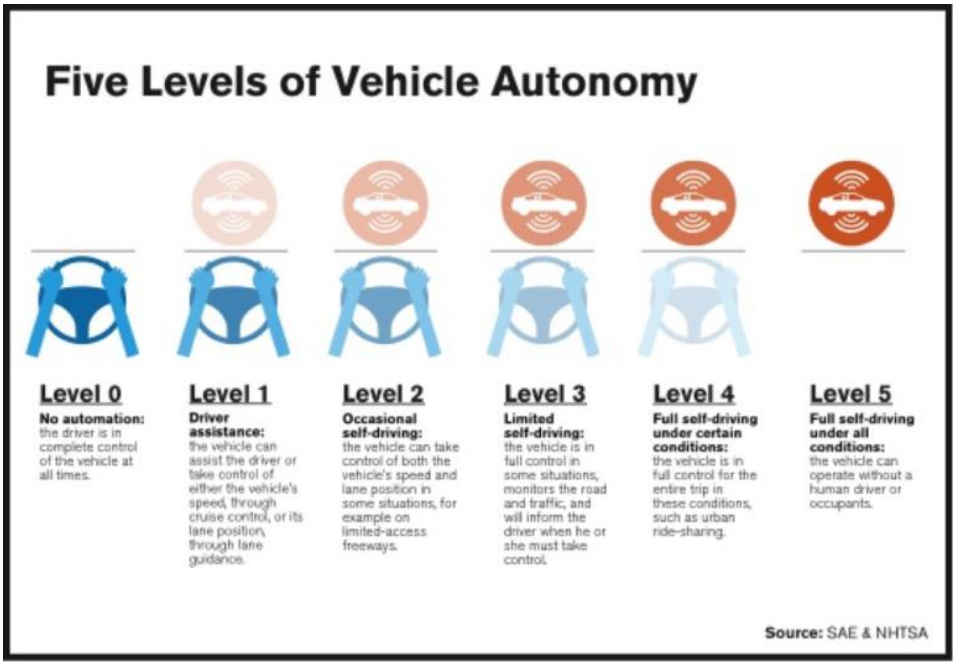

Figure 2: The five levels of autonomy of cars (Bashir & Chatterjee, 2018)

Advantages & Disadvantages

There is a lot of potential in the rise of autonomous cars. The autonomous cars can result in an increased traffic safety. Regarding this safety aspect, in The Netherlands alone there were 678 deaths on the road in 2018, of which 233 deaths were car drivers or passengers (Centraal Bureau voor de Statistiek, 2019). The majority of fatal road accident are a result of human errors. The autonomous cars can make driving much safer, by almost completely minimising the occurrence of human errors. Also the efficiency of driving can increase, this can be a solution to congestion, which will otherwise continue to occur, if not get worse. By cooperative driving this may be tackled, especially on highways (Hussain & Zeadally, 2019). Also, the demand for parking spaces is expected to reduce as a result of

autonomous vehicles. Another advantage is an improved mobility for everyone. Also elderly and children can use the autonomous car independently (Krasniqi & Hajrizi, 2016).

There are also some disadvantages of autonomous cars. For example, the rise of autonomous cars can have a negative impact on employment opportunities, some jobs could disappear. Also the fact that driving can become cheaper and more attractive might lead to an increased use of driving, and therefore possibly more congestion (Krasniqi & Hajrizi, 2016).

2.2 The different scenarios of autonomous driving

Important scenarios about autonomous driving are described by the Kennisinstituut voor Mobiliteitsbeleid (KiM). In their reports Chauffeur aan het stuur? (2015) and Paden naar een zelfrijdende toekomst (2017) four possible future scenarios are distinguished:

- *Mobility as a service: any time, any place*: this scenario assumes a complete autonomous (level 5) vehicle, combined with a high degree of car sharing. Mobility will become a service, cars will be available everywhere. Other public transport modes in the city will disappear.
- *Fully automated private luxury*: this scenario assumes a complete autonomous car (level 5) as well. However, in this scenario cars will remain a private good. The degree of car possession will remain high. The car will take up a lot of space in cities. Traffic in cities has been increased, therefore subcentres will emerge in the city.
- *Letting go on highways:* in this scenario, the car is not completely autonomous (level 3/4). This means that in cities, people still have to drive the car themselves. Also the car will remain a private good. In this scenario, the situation as it is today will not change much.
- *Multimodal and shared automation*: Also in this scenario, the car is not completely autonomous (level 3/4). However, in this scenario car sharing, combined with multimodal traveling, will be the reality. This means that there will be less cars on the road, and thus more space, which can be used for more green in the city.

The future scenario will have a big impact on the spatial design of cities. Also a major factor of influence will be the question if the autonomous car will be connected to other vehicles on the road, or if the vehicles will just use sensors. If the autonomous car is able to ‘’communicate’’ with other vehicles, cars can drive even closer to each other. This will increase the road capacity.

2.3 Conceptual model

As the conceptual model below (figure 3) shows, car sharing and induced demand will determine the amount of vehicles on the road. The extent of autonomy of cars and the extent of connectivity between cars will have an impact on the efficiency of autonomous cars. This efficiency combined with the quantity of cars on the road will determine the change in the use of space in inner cities.

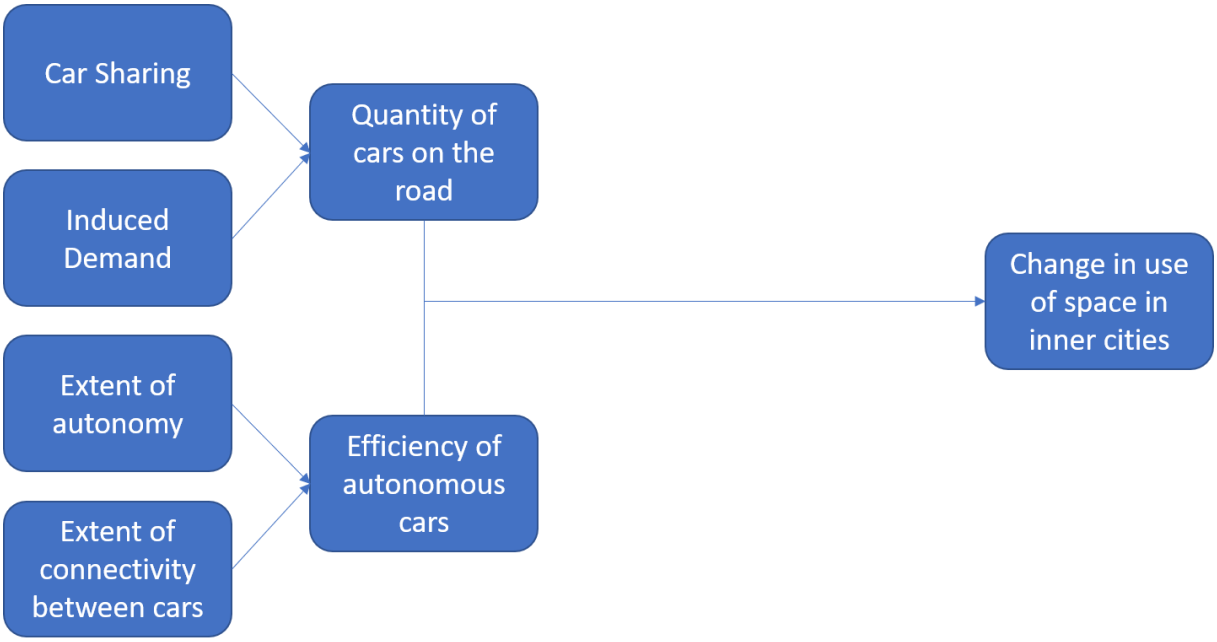

Figure 3: Conceptual model (Source: author)

Chapter 3: Methodology

3.1 Methodology

In this chapter, the methodology of this research is being described. This research is focused on the spatial consequences of the rise of the autonomous vehicles in (inner) cities. To find answers for the research questions, qualitative research methods are used. These methods of research are chosen because the research problem and research questions are complex. Qualitative in-depth research gives more insight in the problem, it will expose underlying reasons, which cannot be found with quantitative research methods. Qualitative research methods allows the researcher to get to know the point of view, from different respondents, from different angles. Therefore, it will result in comprehensive and detailed answers of the research questions (Clifford et al., 2010). The qualitative interviews were conducted as semi-structured interviews, which means that there was the possibility of asking deeper questions. This will result in more useful and detailed information about the topic. Because of the fact that not all the respondents had expertise in the exact same aspect of the topic, not all questions were the same in every interview. Some questions, that matched with the exact expertise of the respondent, were added in some interviews. This means some of the fixed questions were slightly different during the different interviews. The focus of the interview was differed in every interview. The basic interview guide can be found in the appendix.

3.2 Interviews

All of the respondents used for my research are experts in the work field. The respondents are all related to the central topic. In the table below, all the participants can be seen.

Participant	Organisation	Function	Addition	Date
1: Mirza Hotic	Arcadis	Project Manager & Consultant Integral Plans	Hotic contributed to an impact study for AV's	25-04-2019
2: Bert Groot	Saxion University of Applied Sciences	Teacher Spatial Planning and Smart Cities	Groot is an expert in smart cities	07-05-2019
3: Ronald Klaassen	Gemeente Groningen (Municipality of Groningen)	Senior policy adviser	Author of ''The Next City'' (Gemeente Groningen, 2018)	22-05-2019
4: Anonymous	Province of Groningen	Program officer smart and green	Involved in partnerships for autonomous traffic	29-05-2019
5: Anonymous	KiM Netherlands Institute for Transport Policy Analysis	Researcher	Researcher in autonomous vehicles	03-06-2019

Table 1: The interviewed respondents

All of the interviews took around 45 minutes up until 60 minutes to finish. The interviews are all recorded. Later, the interviews have been transcript. After this, the interviews have been coded with Atlas. Ti. The codes are based on different themes within the topic. In this way the interviews can be compared with each other and thus analysed.

3.3 Ethics

This research does not have high ethical risks. The research will not cause any harm and the privacy of the interviewees, if they wish to be anonymous, will be respected.

During the interview process, it is important for the interviewees that they can speak freely and confidentially. Before every interview, the interviewee agreed with recording the interview. The interviews are all taken in the office or company of the respondents, thus, the interviewees could express themselves freely.

All the respondents are experts in their work field, which correlates with this bachelor thesis topic. Because of the fact that all respondents are experts, it is decided to state the names of the respondents in the research, unless they wished to be anonymous. To ensure the carefulness, the data has only been faced to the researcher

Chapter 4: Results

In this chapter the results of the interviews will be discussed, analyses and compared to each other on the bases of different topics around the research question.

4.1 General expectations of the future of autonomous vehicles

To be able to make statements about the extent of which autonomous vehicles will affect space use in inner cities, based on several interviews with experts, it is useful to take into account how the experts see the future of autonomous vehicles in general.

How do the interviewees see the future of autonomous cars:

1: According to my interview with interviewee 1, all four scenarios are four extreme cases. Obviously it is not possible to state which of the four scenarios will turn out to be the most realistic, that is why these four scenarios exist: to give examples of the possible future. According to the interviewee the transition period, where normal cars still exists, will be very interesting. In that phase you can start to see the consequences of autonomous driving. How the future of the autonomous vehicle will look like, is very much depending on the rate of car sharing in the future. According to the interviewee, in the complexity of an inner city, it will always be difficult to integrate the autonomous car.

2: Interviewee 2 believes that autonomous cars will be very much integrated with smart cities. Autonomous cars will have to communicate with each other, and with the city. There are still a lot uncertainties regarding the rise of autonomous car, a lot of research is going on, but it is hard to make predictions. The interviewee hopes we will be heading towards the shared cars scenario, according to the interviewee this will be advantageous for everyone. In this scenario congestion will reduce. Overall, the interviewee is very hopeful in the future of autonomous vehicles.

3: Interviewee 3 states that the development of autonomous traffic still is very uncertain. It is still very difficult to let autonomous cars drive in a complex urban environment. Today, there are already a lot of projects with shared cars. According to the interviewee this trend will continue, especially when the autonomous cars will be introduced.

4: Interviewee 4 sees the shared cars scenario as the future. He/she is mainly optimistic about autonomous cars in rural areas. This will increase the mobility in these low density areas. Autonomous cars could completely replace the loss-making public transport there.

5: Interviewee 5 states that it is not possible to predict a certain outcome. There are a lot of different possible futures. That is the reason why the scenarios are set up, to outline different futures. Interviewee 5 sees huge developments in the autonomous car, but does not think that expecting a completely autonomous car on the short term is realistic. This in contrast to what the media, marketing agencies and the automobile industry makes us expect.

Interviewee 5 does not necessarily state that a shared cars scenario is by definition the ideal scenario. From a social perspective it could be the most ideal scenario, with the least congestion. However, would congestion be considered as unpleasant as today, when every autonomous (private) car is like a second home.

4.2 Space use in cities

In this section the outcomes of the interviews will be discussed. This section is divided in four themes: congestion, spatial consequences, connectivity and cities and change in mobility and structure the of city.

Congestion:

1: According interviewee 1 and the IMPACTSTUDIE AUTONOME VOERTUIGEN (Impact Study Autonomous Vehicles) (Arcadis, 2018), to which interviewee contributed to, the amount of vehicle kilometres in a year will rise without the introduction of the autonomous vehicle. With the introduction of the autonomous vehicle (level 5), the amount of vehicle kilometres in a year will rise even more, so it will get busier on the road. With a car sharing scenario, this will be ninefold compared to a situation without autonomous cars at all. In the case of a scenario in which we all have our privately owned autonomous (level 5) car, the amount of vehicle kilometres would even be the eleven-fold of the current situation. It can be concluded that the scenario with the car as private property ,in which everyone still owns a car, will have the worst negative impact on the accessibility of a city. This is due to the fact that there are more vehicles on the road, which are being used more. However, also in the case of a shared car scenario, the vehicle kilometres will thus rise dramatically. This is a result of the fact that people will use these autonomous cars more often than people use their cars nowadays. The impact study and the interviewee are both stating the probability that autonomous vehicles will be cheaper to use in comparison to cars nowadays. The autonomous car will get more attractive than public transport. People will not walk or cycle to the train station anymore, instead they take the autonomous car. So, these cars will drive more often and will also drive empty on the road.

Inner cities have very complex traffic situations. According to interviewee 1, it is a misconception that autonomous cars will lead to more efficient traffic with less congestion. This may be the case for the predictable highway, but for the inner cities this will not be the case. Congestion may even get worse in inner cities. This is a result of the complexity of the inner city, due to pedestrians and cyclists. Only if different modes of traffic in inner cities would be strictly separated, in a design in which autonomous vehicles do not meet other vehicles on its way, it is possible to reduce the congestion. Also massive technological improvements such as satellite systems and integration of the vehicles with big data can lead to less congestion.

2: According to interviewee 2 we have to use shared cars to prevent congestion in cities.

3: Interviewee 3 points out that the general image of the autonomous car is that it will lead to more space in the city. However, if you look at the past 100 years, every change only led to more mobility. That could also be the case with the autonomous car. Interviewee 3 argues that congestion can increase as a result of a higher mobility of people, and because of the fact that cars can drive around in the city empty. Also, the confrontation of cyclists and autonomous cars is a potential source of congestion according to interviewee 3.

4: Interviewee 4 argues that more space will emerge on the roads, this will mean less congestion. However, interviewee 4 argues that this trend will most likely emerge outside the cities, for example on highways, and not within cities. The interviewee does not see any threats for the spatial quality,

he/she thinks that the use of (electric) bicycles in the inner city will grow at the expense of (autonomous) cars. This as a result of new cycling options that emerge (e-bikes).

5: interviewee 5 states that the case of autonomous cars is very complex. On the one hand autonomous car will be able to drive very close together. A higher traffic intensity on the road is possible, which will lead to less congestion. On the other hand, this only applies for the highway. In the cities itself this is much more complicated, as the traffic is more complex. It is necessary for these cars to communicate with each other. Otherwise strict safety margins are necessary, which could result in even more congestion. Even if cars can communicate with other vehicles, there are still pedestrians and cyclists, which are unpredictable. This can lead to a frustration of the system in inner cities. Another variable is whether shared cars will be the future. If this is the case, in general less cars are needed. The efficiency will increase and therefore the congestion may decrease. The last aspect in this topic according to interviewee 5 is that, because of the increased attractivity of the autonomous car and the increased mobility of elderly, children and disabled, the use of the car will increase. This leads to more traffic and, therefore, possibly more congestion. Concluding, it is very complex with a lot of elements and variables.

Spatial consequences

1: According to interviewee 1, to be able to minimise the congestion problems caused by the autonomous car, different traffic flows should be separated. However, this is not always the most desirable outcome for the liveability of a city. Despite the fact that, according to interviewee 1, the autonomous cars will not solve the congestion problem in inner cities, there will probably emerge more space in cities due to the fact that parking space will not be necessary anymore. Kiss&Ride strips to drop off passengers will replace the parking spaces. Cars will probably go to the next passenger in the case of shared cars, or park at big parking spaces outside of the inner city, around traffic hubs. A lot of current parking spaces in cities can be redeveloped into new destinations, this creates opportunities, for example, for infringement by building houses or offices in these areas. If autonomous cars would remain a private property, the redevelopment of parking spaces could be less, however already now there is the trend of keeping the car away from the inner city. If this trend continues, this will also count for the autonomous vehicle, which means that the amount of parking spaces in the inner city will probably in all scenarios be reduced.

2: Interviewee 2 argues that the impact of the rise of autonomous cars will be very high. With connected communicating autonomous cars combined with a network society, cities can become much more efficient. However, according to interviewee 2 we have to keep liveability in mind. An efficient city is not by definition a liveable city.

Interviewee 2 sees the autonomous car as a change to downsize parking spaces and road profiles. Thus, less space for traffic infrastructure is needed, some spaces can therefore be redeveloped. The interviewee sees here opportunities to increase the liveability of cities, this by creating a diverse and multifunctional city. The vacated spaces should be developed as public spaces with an eye for spontaneous encounters. Also, using this extra space for water and green to tackle the urban heat island effect and water storage problems is an idea. The spatial quality will increase as a result of the rise of autonomous cars.

3: According to interviewee 3, it is not expected that autonomous cars will be parked in the front of every door, because cars drive themselves to parking locations further away. Big parking locations on the edges of cities will appear. This also means that parking locations within the city will disappear. Interviewee 3 believes that the new vacated spaces can be arranged as new public spaces. These new spaces can be filled up with bicycle parking places, or areas with water and green, for example, to tackle environmental challenges in the city. Also street profiles can be reduced. This extra space along the road can be used for more space for pedestrians or cyclists. This will improve the spatial quality of a city.

The interviewee argues that the ideal neighbourhood for autonomous cars is a neighbourhood with as few conflict situations as possible. Traffic flows must be separated. Although these kind of neighbourhoods might be the most efficient for autonomous cars, it will reduce the spatial quality, it is therefore not recommended according the interviewee.

4: Interviewee 4 believes, the demand for parking will decrease and extra space will be available there.

5: According to interviewee 5, especially a future with shared cars will lead to fewer cars on the road, only 10 to 15% of the current amount of cars will be necessary. This will therefore also reduce the demand for parking places. Parking spaces in the city could be redeveloped into bicycle infrastructure and green areas. When all cars on the road are autonomous, also the width of the roads can be smaller.

Also transition zones at the entrances of a city are spatial consequences that will occur when the autonomous car is not yet technically able to drive autonomously in the city itself. This to get drivers pay their attention on the road again.

Connectivity and cities

1: Interviewee 1 argues that autonomous cars will be the most efficient when they can communicate with other vehicles and infrastructure. Therefore, connectivity in cities is needed.

2: Interviewee 2 argues that autonomous traffic will not work without connectivity in cities. This connectivity will have a massive impact on the city. The city will be transformed into a whole system steered by algorithms and big data. Autonomous cars will have to communicate with other vehicles and infrastructure to be successful, according to interviewee 2. Cities that are already working with smart city concepts might be able to anticipate and adapt better to the rise of the autonomous car.

3: According to interviewee 3, smart city concepts concerning big data are very useful to get a view of peoples travel behaviour. Many cities are starting smart city projects, also the city of Groningen wants to start with this on a short term. On the longer term, it is important to facilitate the shift to autonomous cars.

4: No comments about this.

5: According to interviewee 5, communication between autonomous vehicles and the infrastructure is important. Lots of developments are necessary to develop safe communication standards for these cars. All cars should ''speak'' the same language. A digital infrastructure is important.

Change in mobility and structure the of city

1: According to interviewee 1, the emerge of the autonomous vehicles can have a big influence on where people live in the city. Due to the increased mobility, caused by the autonomous vehicle, distance matters less. It is not unthinkable that people will live further away from the city centre. It is possible that the whole composition of a city will change, because of the fact that more people want to live in outlying areas.

2: interviewee 2 argues that the identity of cities and neighbourhoods can change as a result of smart cities and the network society, which are conditions for efficient autonomous cars. Places will become much more multifunctional. Interviewee 2 does not think people will move out of the city as a result of the autonomous cars. Otherwise it would already have happed because of connectivity. The city will always have an attractive force.

3: The interviewee does not expect the autonomous car to change the structure and mobility patterns within the inner city. The bicycle will always be the fastest mode of traveling within the inner city, for example in the case of the city of Groningen. The autonomous car could replace conventional public transport in rural areas. The interviewee states that it will get easier and more comfortable to commute from the rural area, to the city.

4: No comments about this.

5: Interviewee 5 states that when driving becomes more attractive due to the autonomous car, travel distances may increase. This can lead to more people living outside the city and therefore more suburbanisation.

He also points out a consideration between health and comfort. When everyone will use the autonomous vehicle instead of the bicycle, this may be at the expense of health. However, the interviewee states that the trend to green, healthy, bicycle and pedestrian friendly cities will most likely continue after the introduction of the autonomous vehicle.

4.3 Role of the planner

1: Interviewee 1 sees the development of policy for reducing and regulating the amount of (autonomous) car traffic as a solution for congestion in cities. The interviewee sees an adaptive long term policy with multiple paths and multiple development policies as important. Also, policies to make the alternatives of autonomous driving, such as cycling and public transport, more interesting should be made. This could be achieved by subsidising public transport for example. The interviewees view is thus that the government should discourage the use of autonomous cars to prevent congestion. Also the government should try to steer towards a future with shared cars. This can be achieved by starting up pilots, starting campaigns, integrate autonomous (shared cars) into the driving exam and by trying to encourage or force employees to use shared cars. Also cooperation on European level with car manufactures may help to steer the evolution of the autonomous vehicle towards the desirable outcome.

2: Interviewee 2 argues that better legislation is needed for experiments with autonomous cars. Experiments are necessary to be able to improve the algorithms and therefore improve the autonomous car.

According to interviewee 2, shared cars should be stimulated. This can be done by juridical, financial, motivational and communicative incentives. Cooperation between citizens, knowledge institutions, technology developers and the government is very important. Developing policy is important to steer the rise of the autonomous car into the desired direction. Interviewee 2 warns for the fact that a lot of power and money will be in the hands of (technology) companies who do not understand urban development, the government should prevent this. Interviewee 2 also argues that the government should facilitate a good (digital) infrastructure.

3: According to interviewee 3, both the Dutch government as regional authorities are studying and developing knowledge about the autonomous cars. But, also cities as Groningen can set up pilots to test these autonomous vehicles. Problems with congestion in inner cities, as a result of the emerge of the autonomous cars, can be solved with traffic plans. The interviewee sees this as a task for governments/municipalities to make policy for this. With proper road designs, requirements for project developers and regulations/bans governments can influence the rise of autonomous cars. Also in a future of autonomous cars, we still have to encourage people to cycle and walk, instead of taking the (autonomous) car. Making arrangements with employers of big organisations to obligate their employees to use shared cars or the bicycle is a way to steer the rise of the autonomous vehicles into the most desirable direction according to interviewee 3.

4: according to interviewee 4, in the future we will be heading towards the shared cars scenario. To encourage this shift, governmental policy makers could work together with housing corporations. Housing corporations could offer apartments including shared cars, which can be used among inhabitants of the apartments.

5: interviewee 5 argues that the government should consider their role very carefully. The government can facilitate, regulate or invest. A governmental task is, for example, to maintain road signs and lines to facilitate the first generation of autonomous vehicles. Also ensuring good coordination between countries, regarding to communication systems in autonomous vehicles is important. Governments can make policy to prevent the inner city to be full with autonomous cars. The government is, however always dependent on citizen experiences. The interviewee argues that it is not, by definition, necessary to stimulate or steer the development of the autonomous vehicle.

Chapter 5: Conclusion

In this study it is researched how autonomous vehicles will change the use of space in cities and how governments can steer this evolution of the autonomous car towards the most desirable outcome. A qualitative research with five semi-structured interviews has been done.

There are five levels of autonomy, this research is mainly focused on the fifth level of autonomy, which means that cars are completely autonomous (Bashir & Chatterjee, 2018). There are two main future scenarios of full autonomous driving. One in which autonomous cars are still privately owned and one in which cars will be shared. There is a lot of potential in autonomous driving. Traffic safety will increase, driving efficiency is expected to increase and mobility will be available for everyone (Krasniqi & Hajrizi, 2016).

It is expected that autonomous cars will have massive spatial consequences for cities. To find out, interviews have been taken with five experts. The outcomes of these interviews have been divided into 6 topics:

General future:

Interviewee	General Future
1	-All four scenarios are extremes -Future uncertain -Sceptical
2	-Autonomous cars will be integrated with smart cities -Shared cars as the most desirable scenario -Hopeful
3	-Uncertain future -Shared cars
4	-Car sharing as the future
5	-Uncertain future -Not by definition an ideal scenario

Table 2: Key points of expected general future

Based upon the outcomes of the interview, it is clear that the future of autonomous vehicles is still very uncertain. All four scenarios set up by the KiM (2015) are extremes, the future will probably be somewhere in between. Most interviewees indicate that car sharing will be, by all means, the most preferred scenario. This is also in correlation with the article of Chase (2014), where she states that we need to steer towards a future with shared cars to be able to benefit from the autonomous vehicle. There are also contradictions between interviewees. It tends that the researchers (interviewee 1 and 5) are generally a lot more sceptical about the autonomous vehicle than the other interviewees.

Space use in cities:

Interviewee	Congestion	Spatial consequenses	Connectivity	City structure
1	-Congestion in all scenarios of autonomous driving will increase in inner cities -increased use of autonomous cars	-Kiss&Ride strips in cities -More space due to redevelopment of parking spaces	-Connectivity in cities is needed for more efficiency	-Living further away from the city
2	-Shared cars to prevent congestion in cities necessary	-Less space for traffic infrastructure needed -Redevelop parking space into public (green) places with eye for spontaneous encounters -Spatial quality will increase	-Smart cities are crucial for autonomous cars -Communication between autonomous cars is important	-More multifunctional places -No change in structure
3	-Congestion may increase in inner cities due to a higher mobilty and empty cars driving on the road	-Big parking locations will emerge at the edge of the city -Vacated space can be redeveloped into public space with more space for cyclists and pedestrians -Separation on traffic flows	-Smart city concepts are important to facilitate automous cars.	-No change in structure
4	-Less congestion in rural areas	-Demand for parking will decrease	X	X
5	-Very complex in inner cities -Shared cars may decrease congestion	-The redevelopment of parking space into bicycle infrastructure and green spaces -Transition zones at city borders	-Digital infrastructure is important	-More suburbanisation

Table 3: Key points of the expected change in space use in cities

The autonomous car is often seen as a solution for congestion in the media. However, based on the interviews with experts it can be concluded that this might be true on highways, this will definitely not be the case in cities. The autonomous car can even be seen as a source for more congestion, because of the fact that people will use the car more, as a result of the increased comfort and an increased mobility for everyone. Even in the most preferred shared cars scenario, congestion will increase.

The physical city will change as well. According all the interviewees, as a result of autonomous cars, the amount of parking spaces will, depending on the scenario, disappear or will be moved to enormous parking locations at edges of cities. The parking locations within the city should be redeveloped into

green public spaces with room for pedestrians and cyclists. Also the road width can be reduced, this extra space on the street can also be used for cyclists and pedestrians. Ironically, due to the rise of the autonomous car, inner cities can therefore become much more bicycle and pedestrian friendly. This correlates with the research of Fraedrich et al. (2019), according to this research the extra space in cities should be used to encourage cycling and walking, this is exactly what the interviewees points out as well. In some cases a separation of traffic flow can be expected, this should not be done everywhere, because it may reduce the liveability of a city.

It also turns out that connectivity is very important for cities in facilitating the shift to autonomous vehicles. Smart city concepts and the exchange of big data will be necessary to make the autonomous car as efficient as possible.

Among the interviewees there is a disagreement about the question whether autonomous vehicles will change the structure of cities. Some say it will result in more urbanisation, whereas others do not expect a major shift to more rural areas. It is hard to make final statements about this.

Role of the planner:

Interviewee	Role of planner
1	-Long term adaptive policy -Regulation of autonomous traffic -Steer towards shared cars with pilots and campaigns
2	-Stimulation of shared cars -Cooperation between different parties -Digital infrastructure is important -Experiments are important
3	-Pilots -Traffic plans -Encouraging cycling and walking
4	-Encourage shared cars -Cooperation with housing coorperations
5	-Facilitate, regulate or invest in autonomous vehicles -Making policy to prevent congestion in inner cities

Table 4: Key points of the role of the spatial planner

Most interviewees agree that governments should try to steer towards the shared cars scenario, which is considered the most desirable for the liveability. To be able to steer this, a good cooperation between different stakeholders is necessary. Other ways to steer this, is trough policy making, pilots, traffic plans and campaigns. The government also has a role in facilitating the rise of the autonomous vehicle, for example by construct a robust digital infrastructure.

Concluding, the autonomous cars certainly has a lot of potential regarding to the spatial quality in cites. Despite these advantages, there are also a lot of threats, such as congestion. This makes the autonomous car far from the ideal means of transport. Also in future times we still have to fully focus on cycling and walking as transport modes in the city. The trend of keeping the car out of the city centre is expected to continue in the future. In every scenario walking and cycling is considered far more ideal than the autonomous vehicle.

5.2 Recommendations for future research

There is still a lot of uncertainty about the rise of autonomous cars. More research about this topic can reduce this uncertainty. The shift in the system of automobility to a society with autonomous vehicles can be made more predictable by doing more scientific research about it. To be able to make clear statements about congestion and space use in a future with autonomous cars, it is useful to have knowledge about the number of autonomous vehicles that will drive on the road. For future research it might therefore be useful to make concrete predictions about the increase in the number of cars on the road.

5.3 Reflection

There are some points of improvement in this research. Regarding the interviewees for example. For this research, five interviews have been done. More than five interviews would have been a bit more representative, however due to time restrictions this was not possible. Also in the process of interview, it is important to contact possible interviewees in an early stage of the research. Some interviewees do not respond very quickly and have a tight schedule, it is therefore hard to find a suitable moment for an interview. This must be taken into account when planning an interview. This research would have been more complete when also manufactures of autonomous cars would be addressed in this research. However, it turned out that it was very difficult to speak with manufactures of autonomous vehicles.

Chapter 6: References

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Chapter 7: Appendix:

Interview questions:

Questions about different scenarios

1. As the report states, there are 2 different possible scenarios, which includes a level 5 automated autonomous car. A positive scenario, in which shared cars will result in less congestion and a less positive scenario, where cars remain a private property, which will result in more traffic and more congestion. Which of these scenarios do you think is the most realistic? And why is that?

    - Why will there be more/less traffic and congestion on the road in this scenario?

2. Does the scenario with shared cars has a positive effect of land use in cities by definition? And does the scenario with private cars has a negative effect by definition?

The autonomous car is often seen as a solution for congestion. In the report I read that the autonomous car will lead to more lost traffic hours in every scenario. So also in the shared cars scenario will this be the case? Why is this?

Land use

3. Will the rise of autonomous cars result in more or less space in cities?
    - And what is the difference in the shared car scenario and the 'car as private property' scenario in this?

4. What will be the spatial consequences of the arise of autonomous cars
    - And what is the difference in the shared car scenario and the 'car as private property' scenario regarding to this?
    - Where will all the cars be parked?
    - What are the opportunities and threats for cities regarding the rise of the autonomous car?

Spatial planner

5. How can the government or policymakers and planners steer the evolution of the autonomous vehicle to the most desired outcome?
    - How much influence do governments have on the development of these autonomous vehicles?
    - Are governments and planners involved in the development of the autonomous vehicle?

6. Will the street design be adjusted to the rise of the autonomous car, or will the development of the autonomous car be adjusted to the current street design of inner cities?

7. I read in the report that, if the rise of autonomous cars will cause problems, such as more congestion, it will be an option to discourage the use of the private autonomous car. How will this work?

Extra

8. How will the concept of shared cars work, and is it realistic to expect this to be the future?

9. At what term can we expect these cars on the road?