Opleiding ICT in Business and the Public Sector

The Feasibility and Preconditions for Autonomous Driving in Built-Up Areas

for a Thesis

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Abstract

This thesis addresses the question of the feasibility and preconditions for autonomous driving in built-up areas. The automotive industry is experimenting extensively with autonomous driving. Examples include Tesla and Mercedes Benz. To date, experiments are being conducted on special roads designed or designated for this purpose, under predefined conditions. These are roads, which have the character of highways and freeways with separate lanes and relatively few junctions, where different roads meet. In other words, these are roads and conditions, which are not yet representative of the actual traffic image, which is characterized, among other things, by a wide range of various types of road users, roads, traffic rules and associated traffic signs, etc.

This thesis examines what are important considerations for allowing autonomous driving in built-up areas. Different conditions apply in built-up areas than for speedways. The study examines the feasibility in 4 areas: technology, laws and regulations, infrastructure and user acceptance. To investigate, 3 steps were taken. The first step involves a literature study of the phenomenon of autonomous driving. The meaning by this concept, the state of technology development, factors that are relevant for the introduction and enabling of autonomous driving, the advantages and challenges, and infrastructural factors affected by autonomous are explained. In the second and third steps, by means of expert interviews and a document analysis, we examine whether autonomous driving is feasible in Dutch cities and, if so, which infrastructural provisions can be made. To answer these questions, experts were consulted to get their findings and documents are researched to validate the findings. Various infrastructural facilities relevant to the admission of autonomous driving are discussed, comparing highways and urban roads.

This approach finally leads to conclusions on the state of the art and recommendations.

Contents

1 Introduction

1.1 Background

Every year, there are an incredibly high number of deaths and injuries in traffic. Still, 1.3 million people worldwide are killed in traffic on a yearly base[1]. A growth in the world population[2] and urbanization[3] will have an increasing effect on the number of accidents. Apart from the fact that deaths and serious injuries should be always prevented, it also costs society a lot of money. Furthermore, it causes delays and reduces the quality of life. The challenge is to reduce the number of accidents to prevent deaths and serious injuries.

One of the most promising solutions to increase road safety is the introduction of autonomous driving. Several automakers and tech companies are focusing on developing a fully autonomous vehicle (AV). Examples include Tesla, Waymo (Google) and General Motors[4]. Yet, they have not succeeded in getting a fully AV on the road. Multiple factors play a role here. One such factor is the suitability of roads and laws in a country. In 2018, KPMG published a list of the most promising countries in the field of autonomous driving. It assessed countries' on openness and preparedness for AVs. The report of KPMG showed that the Netherlands scored the highest in openness and preparedness for AVs[5]. Among other things, the Netherlands scores best on road infrastructure, which is heavily used and well maintained.
In addition to the suitability of roads, regulations are also crucial in allowing autonomous driving. In addition to its own regulations, the Netherlands also has to deal with European regulations. In July 2022, the European union finalized its legal framework regarding fully automated vehicles with autonomous driving functions. Germany is the first European country to have legal framework for fully automated driving with autonomous driving functions for cars and trucks since July 28, 2022. The framework consists of two parts: the Autonomous Driving Act and the Ordinance Regulating the Operation of Motor Vehicles with Automated and Autonomous Driving Functions and Amending Road Traffic Regulations (AFGBV). These regulations make an autonomous driver a legal driver of a car, eliminating the requirement for a human in a vehicle to drive a vehicle[6].

Since 17th of May 2022, Mercedes-Benz is, as the only one, allowed to start using their DRIVE PILOT system in Germany, which makes it possible to start driving autonomously under certain circumstances on suitable German highway sections, with a maximum speed of 60 km/h. Mercedez-Benz is the first auto manufacturer, which has an internationally valid certification for highly automated driving. A human driver should still be able to take control if the system fails. The system is able to control speed, control distance and guides within the lane. Furthermore, it is able to route course, occurring route events and it can recognize, evaluate and anticipate on traffic signs[7]. The goal is to be able to drive total autonomous in the future. The DRIVE PILOT system has the potential to increase road safety, road efficacy and environmental sustainability[8].

Now that it is possible to drive autonomously on German highway roads under certain conditions, the next step is to expand this to a higher level of autonomous driving and expand the road system for this purpose. Hereby the question raises, why autonomous driving is still not available everywhere. It is understandable that safety is of paramount importance, so that it is important that the expansion will be done carefully. Therefore, a proper research into the possibilities is needed.

This research looks at to what extent autonomous driving is possible within built-up areas and what it requires to makes it possible. Since the Netherlands is one of the countries with the most potential for autonomous driving[5], this research will focus on autonomous driving within urban areas in the Netherlands. The focus here is on 4 factors, which are technology, laws and regulations, infrastructure and user acceptance, which greatly influence the feasibility of autonomous driving within the built-up area in the Netherlands.

1.2 Relevance

As said in the introduction. Autonomous driving can have a promising impact on the road safety. The Netherlands has the goal to have zero traffic deaths a year. A main factor that causes accidents is the human error. Petridou et al.[9] says that in three out of five crashes, driver-related behavioral factors dominate the causation of a motor vehicle accident while they contribute to the occurrence of 95% of all accidents. The Netherlands strive for the "Zero Vision" approach[10], which means that the traffic system does not cause any accident. For this reason, autonomous driving can be promising, since it excludes the biggest factor of having an element: the human being[11][12]. Besides increasing road safety, autonomous driving has the potential to reduce vehicle ownership, allow passengers to be engaged in other activities, reduce parking demand and the congestion that can be caused by searching for a parking place. Furthermore, autonomous driving can reduce gas emissions and energy consumption, due to platooning effects, smooth starts and stops, and reduction of engine starts. This is partly due to the reduction in the size of the vehicle fleet, and through increased coverage and accessibility for the elderly, disabled and those with limited transportation[13]. Studies predict that with a 50% market penetration, AVs will result in a 9,600 lives saved per year, 1.9 million fewer crashes, $50 billion economic savings, 1.6 billion hours saved due to less time traveled and 224 million less gallons of fuels consumed [14].

Yet there is also criticism of autonomous driving cars. Autonomous driving cars also cause accidents. Like an accident on Nov. 24, 2022, is in San Francisco, where an accident occurred in a tunnel at the hands of a Tesla, which was using the "Full Self-Driving" feature[15]. This shows that self-driving cars are not yet capable of completely safe driving. The question here is what can cause accidents like this and how they can be prevented in the future. In addition, this may also be a risk that must be accepted to achieve a greater goal of safety. There are several arguments why self-driving cars will not prevail. Madrigal's article [16] lists seven arguments why autonomous driving might be a success. First, for example, the technology will have to be smarter than humans. The technology will be able to do several tasks better, but will probably have to have more with edge cases. In this, a human is better, given it has more developed judgment. The question is if and when this will be the case. There is also the risk of hacking. The technology can be hacked, which hurts reliability. There are already cars, including non-AVs, that have been hacked in the past. A third argument is that the development, cost and maintenance of an autonomous car will be more expensive, than the revenue from a driverless car and the other benefits. This makes it seem more attractive to have a non-autonomous vehicle instead of an autonomous car. Furthermore, it is difficult to prove that autonomous car is safe. This is because it is the cases where it goes wrong and not the cases where it goes right. A simulator test has the same problem and cannot prove that it therefore works in reality in the edge cases. It is also uncertain when autonomous cars will become a reality. Whether this is going to be within a few years or much longer makes it uncertain for all stakeholders to anticipate and invest in this. As a sixth argument, it is said that, the transition from human-driven to machine-driven is the most difficult step. At that point, the vehicle can no longer ask for help and an autonomous vehicle is fully responsible for every scenario. The question when can you say your vehicles is fully autonomous. Finally, a development like the autonomous car may actually lead to more traffic and emissions. A development of a technology like the autonomous car has proven in the past to have far-reaching consequences and change in lifestyle as a result. It may cause the reaction that people will favor AVs, causing an increase in use, with the consequences that this entails. If left to the market, this could be a realistic scenario. This leaves other and better alternatives for what they are.

Research is needed to assess the feasibility of autonomous driving. Current literature mainly focuses on the current state regarding feasibility, but still lacks recommendations, which can contribute to the feasibility of autonomous driving. A clearer picture of the possibilities offered by autonomous driving and the current challenges and shortcomings, can help guide where further research, investment and work is needed. Directions, identified by KPMG[5] and Alawadhi et al. [17] that are crucial for the feasibility of AVs in urban areas are technology, laws and regulations, infrastructure and user acceptance factors. This research will focus on these factors to investigate the changes and needs of AVs in urban areas. To introduce autonomous driving everywhere, all these factors must be ready for it. Technology is driving this development. Developers of AVs, who will have to ensure that self-driving cars are able to cope with other factors than those that currently apply on German roads where autonomous driving is already partially practiced[18]. Furthermore, the legal field will also be interested in the potential dangers of and requirements for autonomous driving, in order to have a clear separation of liability in cases where things go wrong[19][20]. The infrastructure is also important which may require investments that must be prepared or made now so that by the time autonomous driving is ready. Consider designers of infrastructure, who will have to take autonomous driving into account[21]. Finally, politicians and users, who have to decide whether to allow autonomous driving, should be well informed about the consequences of and requirements for autonomous driving[17]. This research helps gather information on the opportunities, feasibility, hazards, challenges and needed changes to enable autonomous driving within built-up areas.

In 2018, KPMG published a report in which it researched the readiness of countries in autonomous driving[5]. It ranked 20 countries on openness and preparedness on autonomous driving. The 20 countries were selected on their economic size and progress in adapting AVs (AVs. The Autonomous Vehicles Readiness Index (AVRI), is based on four pillars: "Policy & Legislation", "Technology & Innovation", "Infrastructure and user Acceptance". In terms of Infrastructure, the Netherlands scored the highest, given its heavily-used, well-maintained road network, rated as being among the world's best by the World Economic Forum and the World Bank. In addition, it has the highest density of electrical vehicle charging points, with 26,789 publicly-available points in 2016 and also has high-quality wireless networks too. This makes the Netherlands an interesting country for autonomous driving. It also scored high on user acceptance, second only to Singapore. Also, the Netherlands scores as the highest of the 20 in the World Economic Forum's technology readiness rating and has a benevolent government, given its investments in infrastructure, innovation and, for example, traffic lights that can communicate with vehicles. Since the Netherlands scores high, this study chooses to focus on the Netherlands to study the feasibility of driving autonomous in built-up areas.

1.3 Research Content

This study investigates the feasibility of AVs in urban areas. This research is as follows. First is a theoretical framework, in which there is research on what can be found in the literature about autonomous driving, the pros and cons and the four factors that affect the feasibility of AVs. In the problem statement there is an explanation of the gap found in the literature. From this, the following problem statement was created: "Autonomous driving is a new technology, which has many difficulties and problems that must first be overcome to successfully introduce autonomous driving in the Netherlands". From this, the following research question was created, in which this research answers. The research question is: "What influence do technology, laws and regulations, infrastructure and user acceptance have on the feasibility of autonomous driving in (Dutch) urban areas?" This research question focuses on Dutch urban roads because it has been indicated that the Netherlands is currently the best suited country for autonomous driving, according to KPMG[5]. To answer the research question, both an expert interview and document analysis were conducted. In Research Approach, there is an explanation of the method of this research and its shortcomings. In the expertise interviews, different dutch experts were asked about the feasibility of AVs in the Netherlands with respect to infrastructure and the document analysis validates these findings. Finally, the findings from the literature are compared with the findings from the expertise interviews and the document analysis in Research Results. This results in answers to the research question and recommendations needed to increase the feasibility of AVs in urban areas in the Netherlands.

2 Theoretical framework

The theoretical framework tries to answer questions on the feasibility of having autonomous cars in Dutch urban areas. It discusses the literature on autonomous driving starting with the definition, AV potentials and challenges, followed by discussing the four factors that influence the feasibility of AVs in Urban areas, which are technology, law and regulation, infrastructure and user acceptance.

2.1 Definition

First, definitions of autonomous driving according to several articles are discussed here.
Beiker et al. [19] has defined the different levels of system integration as "warning and information" (1), "assisted driving" (2) and "automated driving" (3). "Warning and information" refers to a passive system that helps the driver to maneuver the vehicle in certain situations. Examples are navigation system, park distance information, lane departure warning. "Assisted driving" involves specific driving tasks, that are automated for specific use cases, such as adaptive cruise control, heading control and lane change assistance. With "automated driving", all driving tasks are automated for specific use cases. For example automated highway and automated parking.

Another definition according to Wachenfeld et al. [22] defines autonomous driving as "the driving task is performed in a way that is called fully automated". This definition is extended by the assumption that "the machine behavior stays within an initially set behavioral framework". By "fully automated" is meant: "the fourth level of automation according to BASt" (a German Federal Highway Research Institute). This institute describes the fourth level of automation as follows:
"the system takes over lateral and longitudinal control completely within the individual specifications of the application.

- The driver does not need to monitor the system.
- Before the specified limits of the application are reached, the system requests the driver to take over with a sufficient time buffer.
- In the absence of a takeover, the system will return to the minimal risk condition by itself.
- All system limits are detected by the system, the system is capable of returning to the minimum risk condition in all situations."

As mentioned in the previous definitions, there are more defined lists of levels of automation. The article by Miao et al. [8] provides an overview of all the levels of driving automation according to Society of Automotive Engineer (SAE). They identify 6 different levels of automation driving where level 0 is fully manual and level 5 is fully autonomous. The levels are: no driving automation (0), driver assistance (1), partial driving automation (2), conditional driving automation (3), high driving automation (4), full driving automation (5). For the levels 0 to 3 means that when automation fails, the vehicle still falls back on the driver for urgent events. For level 4 and 5, the fallback to an automated system. The levels are shown in figure 1.

Level	Name	Fallback When Automation Fails
0	No Driving Automation	Driver
1	Driver Assistance	Driver
2	Partial Driving Automation	Driver
3	Conditional Driving Automation	Driver
4	High Driving Automation	Automated system
5	Full Driving Automation	Automated system

Figure 1: Autonomous Driving Levels [8]

Finally, the article of Brenner et al. [23] uses the definition and levels made by National Highway Traffic Administration (NHTSA), the civil regulating authority of the USA. According to the article of Brenner that definition is used as the "de-facto standard World-Wide". In comparison to the definition used by Miao et al. [8], this definition only has 5 levels, which are: "No-Automation" (0), "Function-specific Automation" (1), "Combined Function Automation" (2), "Limited Self-Driving Automation (3) and Full Self-Driving Automation" (4). "No-Automation" means that the driver is complete and sole control over the primary vehicle controls (brake, steering, throttle and motive power) at all times. "Function-specific Automation" is automation that involves one or more specific control functions. Such as electronic stability control or pre-charged brakes, where the vehicle automatically assist with braking. "Combined Function Automation" involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. For example adaptive cruise control in combination with lane centering. "Limited Self-Driving Automation" level says that vehicles at that level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. Hereby the driver is expected to be available for occasional control, but with sufficiently comfortable transition time. Finally, there is the "Full Self-Driving Automation" level, where the vehicle is designed to perform all safety critical driving functions and monitor roadway conditions for an entire trip.
This article maintains Miao's [8] automation levels.

2.2 AVs Potentials

AVs have the potential to yield several advantages. This section names the benefits found.
Beiker et al. [19] mentioned three main challenges of individual mobility, which are a motivation for autonomous driving: "safety", "efficiency" and "mobility". According to the article, which is written in 2012 states driver error is by far (95%) the most common factor implicated in vehicle accidents. Driver distraction is a major cause. Autonomous driving may therefore be the most promising tool alongside education, communication and enforcement[19]. Robots are never tired, always attentive and are able to carry out the instructions under all conditions. Furthermore, some safety systems can respond to dangerous situations, such as breaking unexpectedly, or detecting people or obstacles around the car[24]. For example, expectations based on insurance numbers are that the automatic emergency brake assistant reduces rear-end collisions by 38%; the lane keeping

assistant reduces accidents by 4.4% and the lane changing assistant by 1.7%[23].
The second motivation is efficiency. Traffic congestion leads to unproductive time, unnecessarily burnt fuel and a financial loss of $87.2 billion per year in the United States. Furthermore, it could reduce a portion of the emissions problems and improve energy and space use. Autonomous driving can help to harmonize traffic flow by more precise anticipation and an inter-vehicle collaboration. A decrease in the space needed between cars can increase the capacity on roads and make it easier to manage the traffic flow. [19][24]. The final main challenges identified in the article of Beiker et al. [19] is that mobility can make adolescents, elderly citizens, disabled citizens and non-licensed drivers more independent[23].
Other benefits are for example that the time spent in the AV can be used for other things, such as entertainment, work or rest. Other benefits are related to inner city traffic and city planning, where less parking places are needed and be used for other purposes. Finally, Brenner et al. [23] identified a mega trend, which show the influence and success of the "share-economy". Examples are Uber and AirBnb. Many young people see themselves as participants of that share-economy, which will have an effect on the mobility sector. This in combination with the mega trend of a growing environmental awareness and the desire of more and more people to reduce their carbon footprint, increases the speed of change. AVs can be very useful in such a "shared economy", which will also increase its efficiency and so the carbon footprint.

2.3 AVs Challenges

Autonomous driving is still in a developing stage. The literature has identified several challenges. The ones that are found will be discussed here. Starting with Beiker et al.[19] and who discussed some legal challenges. For example, the legal challenges that will raise when autonomous driving will lead to accidents. Questions of who or what is responsible for what is responsible will be more complex than before, where the options for a cause were human failure, technical failure, environmental conditions or a combination of them. Autonomous cars make decisions, that are no longer seen as technical failure. Artificial intelligence will now act on behalf of a humans with life or death consequences. It is unclear how courts, regulators, and the public will react to accidents involving robotic cars. Even if AVs will lead to less accidents, determining who will be responsible is still a complex issue. One of the challenges mentioned by Brenner et al. [23] is that there may be resistance to new technology. Even when experts are in favor of it, societal resistance can still lead to the end of new technology. An example of this is nuclear energy.

More challenges are described in the article made by Campbell et al. [24] who researched the challenges faced by teams, competing in the DARPA Urban Challenge (DUC), while driving in urban areas. The DUC is a competition in which teams demonstrate the capabilities of their autonomous cars. The article describes approaches, lessons, challenges and bearing-term research challenges. The goal is to find technologies that can contribute to improving vehicle safety, exploiting intelligent road infrastructure and enabling robotic vehicles operating in human environments. Six key challenges have been identified.
The first one is "system integration". AVs faces several integration challenges. There are constrains for navigation systems, such as location, field of view, mounting type of the sensors and cooling and power for the systems. One challenge is autonomous driving with fewer, cheaper and conformal

mounted sensors, all of which must work simultaneously. It is essential that the integration of the hardware and software is done in such a way as to ensure sufficient robustness to component failures.
The second challenge in the article of Campbell et al. [24] is "prediction and trust". AVs are not always able to predict the situation right. Where as humans need only a small amount of information, such as for example eye contact, to predict the situation, autonomous cars need much more complete information to do the same. Areas of research to address this problem include hierarchical graph models, that build upon the reliable, lower level tracking, and representations to capture the higher level information required for planning. Humans can also more easily tell what the difference is between a good and a dangerous or unaware behaving driver. Another thing is that human drivers rely on the other driver to obey the traffic rules. This is more difficult for an autonomous car. The challenge is how the AV deals with some uncertainty.
The third challenge concerns "interactions between agents". With agents, the different road users, that are able to digitally connect with other road users are meant. Increases in AV capabilities and infrastructure, which supports communication between vehicles will play an important role in the future. Consider sharing information about driving decisions and intentions, as well as available information about obstacles or hazards. For this communication robust agreement protocols should be developed. The challenge for this type of technology is how it would deal with faulty or simply driven vehicles by human drivers. There are some issues that should be resolved first. For example safety, where AVs must be able to identify human driven vehicles and then not drive into them even if they do not follow the rules. Another issue is how people will behave when AV are on the road. People already drive poorly when there are other human drivers on the road. But how will that be if no one is driving anymore? AVs should be able to deal with that. Furthermore, how should it deal with non collaborative vehicles, where, it is used to having only collaborative vehicles on the road.
The fourth challenge is "Learning". The DUC also showed the challenge for AVs to learn from mistakes or previous experiences. The article illustrates examples of challenges for future autonomous driving, including the need to improve the ability of the robots to learn and adapt to the environment and learn from past experiences at all levels of the planning architecture. Humans are able to learn easier from previous actions, where AVs are not good at identifying a problem and avoiding it in the future.
The fifth challenge is "scaling up". The moment autonomous driving is allowed in the real world compared to the test environment, the effects of scaling up will have to be considered. Challenges involved are speed increase, which affects reaction time and obstacle density. Speed affects response time, which consists of (i) perceiving the environment, (ii) processing the sensor data, (iii) arriving at a control decision, (iv) commanding the actuators, (v) getting the actuators to respond, and (vi) getting the vehicle to respond. The ratio of time changes as the speed itself changes. This must be taken into account constantly. Moreover, with increasing speed, other factors such as skidding will also have to be taken into account, with swerve sometimes being a better way out. Systems will have to be adjusted accordingly to make the right decision. Furthermore, traffic density plays a role in scaling up. The problems that arise are different for cars traveling in the same direction (highways) compared to cars crossing each other (within cities). On highways, unsafe maneuvers are more often performed, assuming that cars always travel in the same direction and do not brake randomly. This is where "platooning" can play a role, where cars work together in tightly coupled formations and communicate among themselves. This does not apply to an urban environment, where uniform traffic flows cannot be assumed and obstacle density is much higher. Detection

and tracking algorithms are of much greater value/importance here. Furthermore, models are also needed, to help AVs determine what actions to take in which situation. There is still a lot of research to be done on this. Also, in inner cities it will have to deal (much more) with pedestrians, dogs, cyclists and other moving objects. There is a big difference in "seeing" an object and "knowing what it is doing."

The last challenge, discussed in the article of Campbell et al. [24], is "verification and validation". Verifying that systems are secure and robust presents significant technical challenges. The right tests and systems need to be developed for this purpose in order to do this as well as possible. However, it is not possible to test every situation or combination of events, especially because of the complex dynamics of multiple vehicles. Despite advances in this area, more research is needed on methods that can contribute to reliable verification methods.

Finally, the article states there is much potential in software and hardware development. In which the functionalities of the vehicle itself will be improved. Furthermore, network and communication device technologies will also contribute to energy management and inter-vehicle and vehicle-infrastructure communication. Much research is being done on how this can contribute to highways and transportation systems. However, this lacks research on vehicles and infrastructure within built-up areas (on non-highways).

2.4 Feasibility factors

The next section focuses on the feasibility of AVs. There are 4 factors identified, which relate to the feasibility of AVs according to KPMG[5] and Alawadhi et al.[17]. These 4 factors are: technology, law and regulation, infrastructure and user acceptance. The following subsection discusses these 4 factors further.

2.4.1 Technology and current state

Here we discuss the first factor, technology, in the context of autonomous driving. It is first important to know what current technology is capable of[25]. In this part, technology that is already available to make autonomous driving is discussed.

Articles that have described the technology of AVs and the infrastructure around are the article of Brenner et al.[23] and of Miao et al. [8]. Brenner et al. describes AVs as "cyber physical systems", with which they mean a combination of a physical product and an associated computer supported information processing. AVs can be described by the structure "Entry – processing – output". This involves entering data collected by sensors. Sensors is an important aspect in the relationship between technology for AVs and infrastructure. Sensors are responsible for mapping the infrastructure around the AV and detecting other environmental factors, which affect the AV such as objects and weather conditions. Examples of sensor technology, embedded in Audi's RS 7, are GPS, ultrasonic sensors, radar- and camera systems. The ultra sensors are used for nearby area's, which can assist when parking. Radar systems are effective for greater distances and are used for automatic vehicle interval control. Infrared sensors are useful at night. The camera systems can capture and identify objects, such as other vehicles, other motorists or pedestrians and follow these. The GPS system is a further part of the sensor technology, which recognizes the location and movements of a vehicle. Research now focuses on the development of sensor systems and software for object recognition,

object identification, object traction and the prediction of object behavior. Machine learning and deep learning is expected to play a role in this development and thus in recognizing infrastructural elements and environmental factors. Receiving complete and reliable information is crucial for the AVs. Infrastructure can play a role in this, by providing a clear picture and responding well to available sensors. The development of sensors, as well as their cost, partly determine the role of infrastructure.
The article of Miao et al. [8] has described different types of technology, that can be used for autonomous driving. The article says that some vehicles already contain sensors that provide basic functionalities of autonomous driving. Examples are advanced sensors including "IP (Internet Protocol) Camera", "Radar/LiDAR" (Light Detection And Ranging of Laser Imaging Detection And Ranging), and "Advanced Driver Assistance Systems (ADAS)". They can be used for the basic functionalities of autonomous driving. These sensors are crucial for safety, but are easily impacted by bad weather, poor lightning, conditions or "non-line-of-sight obstacles (NLOS)", such as buildings, trees and hills. LiDARs is now considered as one of the main sensors, but has a high costs. Besides the focus on improving these sensors, the industry should also try to reduce the costs of it[26].
The input of the sensors is compiled into an image of the environment. The destination based on the entry is put into the "GPS system", which can calculate the route to it. The system processes the entry into commands for the car, which takes place in real time. An extra important part could be the interface which communicates with the user, for example about problems, warnings, etc. It can communicate that the user have to take over control. Examples of these interfaces are warning lights, which are projected into the windscreen, acoustic signals or vibration of the steering wheel with or without automatic steering correction if the vehicle begins to leave the designated lane. Other interfaces which are of importance are interface of highly automated and later AVs with the environment, for example pedestrians[23]. In addition to these sensors and processing systems, connectivity is also seen as important aspect between AVs and its infrastructural and environmental factors. Connectivity is a potential way to increase the safety and comfort of level 3 and 4 driving. Vehicles can be interconnected, which can increase the level of driving autonomy. "C-V2X" are cooperative systems that can enable vehicles to communicate with other vehicle's, infrastructure, pedestrian and network to improve road safety and road efficiency. Cooperative "C-V2X" systems are "vehicle-to-vehicle (V2V)", "vehicle-to-infrastructure (V2I)", "vehicle-to-pedestrian (V2P)" and "vehicle-to-network (V2N)"[27]. These networks communication systems makes it is possible to introduce "artificial intelligence (AI)" technology. With AI, a collision avoidance system could be adapted to the environment and facilitate fast and accurate decisions[23][8]. "C-V2X" technology can strengthen safety, when it is adapted to future and current vehicles. An example of a solution is "Vulnerable Road User Collision Warning (VRUCW)", which is of the most important "C-V2X" system solutions. This system should be installed around infrastructure. It can help by scanning the environment and communicating potential hazards to vehicles. It helps to avoid accidents. The article of Miao et al.[8] concludes that VRUCW application is workable and can increase road safety for autonomous driving based on testing and demonstrations in open field. This will require setting up infrastructure, such as cameras and sensors, capable of scanning the environment. It is also necessary to investigate which traffic situations are suitable for this system.

In the article of Behere et al.[28], who presents the principal components needed in a functional architecture for autonomous driving. Key elements are discussed for which they gave a proposal for a

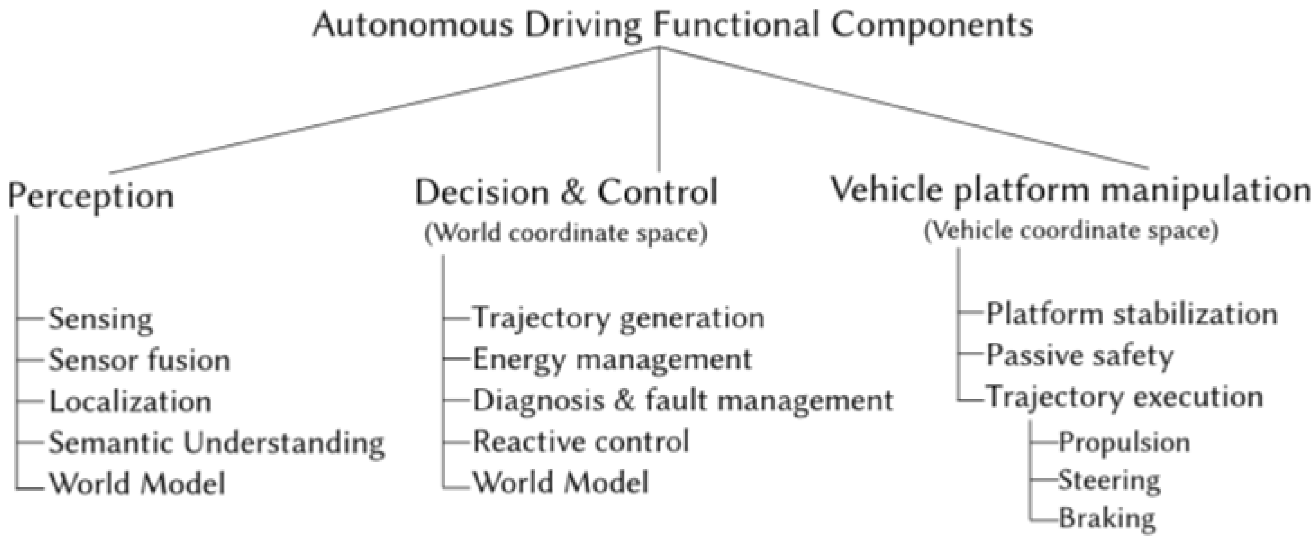

Figure 2: Components of a functional architecture view (FAV) of an autonomous driving system [28]

division of these key elements in architectural layers and they proposed a functional architecture for autonomous driving. The three categories are: perception, decision & control and vehicle platform manipulation. Perception is about the perception of the external environment/context in which the vehicle operates. The decisions & control of the vehicle is about motion, with respect to the external environment/context that is perceived. The third category is vehicle platform manipulation which deals mostly with sensing and actuation of the ego vehicle (vehicle under test), with the intention of achieving desired motion.

With "perception" they identified: sensing, sensor fusion, localization, semantic understanding, world model. "Decision & control" has the components: trajectory generation, energy management, diagnosis & fault management, reactive control and world model. "Vehicle platform manipulation" entails: platform stabilization, passive safety and trajectory execution, such as propulsion, steering and braking. The three categories and components are shown in figure 2.

Sensing is the states of the ego vehicle and those sensing the states of the environment in which the ego vehicle operates. Sensor fusion considers multiple sources of information to construct a hypothesis about the state of the environment. Localization is responsible for determining the location of the vehicle with respect to a global map, with needed accuracy. Semantic understanding is the component in which the balance shifts from sensing to perception, which is meant that the semantic understanding component can include classifiers for detected objects, and it may annotate the objects with references to physical models that predict likely future behavior. The world model component holds the state of the external environment as perceived by the ego vehicle.

The trajectory generation component repeatedly generates a set of obstacle free trajectories in the world coordinate system and pick an optimal trajectory from the set. Energy management manages energy consumption in the car usually split into closely-knit sub-components for battery management and regenerative braking. Diagnosis and fault management refers to identifying the state of the overall system with respect to available capabilities. The identified state would be used

to influence behavior like redundancy management, systematic degradation of capabilities, triggering transitions to and from safe states, and potential driver handover. Reactive control components are used for immediate (or "reflex") responses to unanticipated stimuli from the environment.
The platform stabilization components are usually related to traction control, electronic stability programs, and anti-lock braking features. Their task is to keep the vehicle platform in a controllable state during operation. The trajectory execution components are responsible for actually executing the trajectory generated by Decision and Control. It executes the propulsion, steering and braking functions of the vehicle.
These are all components, which are part of an AV and are relevant to autonomous driving.

The early mentioned technology of AVs is of major importance to the adoption of AVs, but it is not the only factor that is relevant for the adoption of AVs. The article of Alawadhi et al. [17] has researched factors that are of influence on the adoption of AVs. It has identified four readiness categories, which are: technology, infrastructure, legal and user acceptance. According to the article of Alawadhi et al. [17] the technology is an important category. The article adds that there are multiple aspects of technology that are relevant to the readiness of AVs for the adaption, which are the vehicle technology itself, safety and ethics. AVs are supposed to perform tasks such as automatic braking, lane-keeping and adaptive cruise control as well as imaging, in other words detection of the area through which the car is driving. For that it requires detection devices consisting a camera, radar, lidar and other sensors installed to detect the cars environment. Furthermore, a navigation system is needed to identify the cars position by using GPS and Galileo. The sensors should work under any circumstances, like in conditions of rain, sunlight, shadow and intensity of light. The systems should be used to derive information from its environment that will subsequently be interpreted by the road detection system installed in AVs. Moreover, user safety is always an important requirement when introducing new technology. Safety needs to be well tested to guarantee the safety of the user and pedestrians or other road users around the AV. The adaption of the technology is highly dependent on this aspect. Even in extremely and unexpected driving conditions. Machine learning could play an important role in it, all though it is still facing challenges there as well. Another sub-factor related to the technology is ethics. For example, how should an AV, respond to dilemma's? This should be programmed, but depends on the law as well.

2.4.2 Laws and Regulation

The second main readiness character identified by Alawadhi et al. [17], is "legal readiness". Regulation is key for the development and adaptation of AVs. It influences the issues related to "policy and regulation", "liability", "privacy and cybersecurity". "Policy and regulation" are an obvious aspects when it comes to legal readiness. After all, the implementation of AV requires the creation of policies and regulations. Decisions on these must be made by policymakers, scientist and professionals. Policies must ultimately be aligned with the new autonomous driving. In addition, laws must avoid conflicts, and there must be consensus on the limits of liability and privacy, technologies must be defined and prioritized. Matching "liability" is very important when it comes to safety. People cannot simply be held responsible for mistakes made by a machine in general, and thus for mistakes made by AVs. On the other hand, a human can still exercise control over an AV. There does lie a great responsibility on manufacturers for reliability and security of AVs. Third parties also play a

role in this. They may already waive responsibility in the contract. Standards will be needed, to assess who is liable and how to deal with it. It is ultimately possible that the liability is shared among various parties involved such as drivers, vehicle owners, data providers, manufacturers, and sensor suppliers.
Another issue is privacy. AVs contain a lot of information that is collected in various ways. Through sensors, information about routes and destinations, driving habits and occupants and owners is collected. Storing, maintaining and protecting the data is a big responsibility for manufactures, among others. User desire also plays a role. Users will need information to make choices about their needs. AVs depend on technology and internet connection. This makes it a target for hackers and cyber attacks. Also, the system is highly interconnected, which makes it an interesting target. A hack or cyber attack can have major consequences, making cybersecurity of great importance. The risk of cybercrime is a major concern for insurers, regulators and policy-makers who need risk assessment method. Thus, the digital infrastructure will have to be well protected from hackers and it will have to be considered that software problems can lead to impassable paths. Privacy is also important for the infrastructure, with infrastructure sensors having to take this into account.

2.4.3 Infrastructure

The third main readiness factor identified by Alawadhi et al. [17] is infrastructure. The article discusses the role of communication, technology of roads and traffic signs and the cost of infrastructure in adaption. Communication is needed for navigation of AVs. It is based on information that they receive from onboard sensors and though vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication systems. Regarding the technology of roads and traffic signs, the article says that AVs need a different road infrastructure that is more compatible with AVs than classical roads. In addition, traffic sign recognition software should be improved with updates. The article also suggests that at a later stage, traffic lights, yield signs, streets signs, speed limit signs and other physical infrastructure will no longer be needed. They will be replaced by digital versions. Custom infrastructure for charging stations and parking lots will still be needed. Charging stations infrastructure dependents on locations, fleet size, waiting time, impact of charging time and the management of trip demands. About the costs of infrastructure, the article of Alawadhi et al. [17] says that the necessary upgrades will be expensive. Thus this will be an important factor in the decision-making process of introducing AVs. Infrastructure upgrades should ensure uninterrupted, predictable, safe and efficient traffic flow. In addition to the cost, it will also be time-consuming operation, to implement the infrastructural upgrades and will therefore be a bottleneck for implementation, compared to in-vehicle-automation developments. Other costs to consider are the cost of developing specialized methods, training expert personnel, deploying equipment required for operating and maintaining an infrastructure for the AV system and infrastructure for charging the AVs.
This subsection focuses on what the literature says about the role that infrastructure has on the feasibility of AVs within built-up areas. Several articles have researched the effects of AVs on infrastructure and its readiness.
Alawadhi et al. [17] studied the social acceptance for autonomous driving, in four areas: technology, infrastructure, laws and regulations and the user. In the infrastructure category, they examined the state of road and road sign communication technology and infrastructure costs.
Another article, that has researched the impacts of AVs on multiple branches of the physical

infrastructure is the article of Othman [13]. The article analyzes impacts on geometric design, by analyzing the use of autonomous cars on stopping sight distance (SSD), passing sight distance (DSD) and horizontal and vertical curve design (1). Furthermore, the article analyzes the impact on design of parking lots (2), pavement design (3), design of bridges and infrastructure requirements as well as new risks or challenges resulting from the introduction of AVs: such as required safe harbor areas, the need for traffic management technology, and required signage and marking (4). An article by Liu et al. [29] concerns a literature review of roads infrastructure requirements for Connected and Autonomous Vehicles (CAVs). They looked for aspects that should be upgraded to successfully introduce autonomous cars on the road.
Kockelman et al. [30] conducted research on the traffic impacts and infrastructure needs of AVs. They made a list of technologies that are part of autonomous driving and identified the infrastructure needs for the technology to function properly. This was worked out for 20 different technologies. Some technologies don't require infrastructure facilities, because they are vehicle-based features that depend only on the sensing of surrounding vehicles. Other technologies do depend on infrastructure. Mentioned are road marks, traffic signs, possible dedicated lanes, beacons & guide walls (for automated assistance during roadworks and congestion), lighting and parking facilities. Figure 3 summarizes their findings combined with infrastructural costs. The technologies that require the most infrastructure modifications are traffic sign recognition, automated assistance in roadwork and congestion, auto-valet parking and driverless cars.

Finally, Saeed [31] conducted research on road infrastructure readiness through a literature review, a stakeholder survey and a case study. The survey was conducted among technology developers, highway agencies and road users. The highway agencies were asked about certain topics such as the infrastructure readiness and needs for AVs. The article also considers different phases for adaption, with a transition phase and a fully autonomous era. Like Johnson et al. [27], that discusses the transition period where vehicles with different level op automation should share the road. He says that options should be considered where all type of interactions are possible or that the vehicles with different level op automation are separated from each other.
The findings of these articles are discussed below. First some general factors, which are applicable to almost all roads.

<u>Communication</u>
The first relevant infrastructural factor is communication. AVs are able to share information and communicate with other devices. Regarding communication the article of Alawadhi et al. [17] found that information and communication technologies as well as transport networks will have a positive effect on safety and sustainability. A combination of communication between vehicles, named vehicle-to-vehicle (V2V), and navigation systems that learn from onboard sensors, called vehicle-to-infrastructure (V2I), can help make navigation safer and more efficient without the participation of humans. These V2V and V2I systems together are called vehicle-to-everything (V2X). V2X communication must also integrate additional traffic participants, such as bicyclists or pedestrians. According to the article infrastructure should be adjusted to accommodate this communication between vehicle and infrastructure. Therefore, sensors and internet connectivity are required. Examples of sensors that are necessary for V2I are loop detectors and magnetic detectors; examples of over-roadway sensors are cameras, radars and ultrasonic, etc. They monitor traffic to make the traffic flow smoother. Furthermore, examples of needs for internet connectivity are

Table 2.4: Infrastructure Needs Evaluation for Different Technologies

#	Technology	Infrastructure Need	Infrastructure Cost
1	Forward Collision Warning	None	None
2	Blind Spot Monitoring	None	None
3	Lane Departure Warning	Lane marks	Low
4	Traffic Sign Recognition	Traffic sign	Moderate
5	Left Turn Assist	Lane marks	Low
6	Adaptive Headlight	None	None
7	Adaptive Cruise Control	None, possible dedicated lane	Depends
8	Cooperative Adaptive Cruise Control	None	None
9	Automatic Emergency Braking	None	None
10	Lane Keeping	Lane marks	Low
11	Electric Stability Control	None	None
12	Parental Control	None	None
13	Traffic Jam Assist	Lane marks	Low
14	High Speed Automation	Lane marks, traffic sign	Moderate
15	Automated Assistance in Roadwork and Congestion	Lane marks, beacons, guide walls	Relatively high
16	On-Highway Platooning	Lane marks, traffic sign	Moderate
17	Automated Operation for Military	None	Unknown
18	Driverless Car	Lane marks, traffic sign, lighting	Relatively high
19	Emergency Stopping Assistance	None	None
20	Auto-Valet Parking	Parking facilities	Relatively High

Figure 3: Source: (Kockelman, et al., 2017 [30]

mobile networks such as 4g or a 5g or WIFI-based facilities [29]. Internet and WIFI also need to be expanded in rural areas, which currently lack connectivity, to support AVs operations [31]. The vehicles and communication systems depend on electricity and batteries, which makes charging an important aspect too [17].

The support and adaptation for AVs is also dependent on the possibility of detecting road conditions, such as wet road surface and snow. Vehicles own detection systems using sensors or communication between vehicles or with infrastructure should play an important role in this regard [17].

The communication systems could also be used for real-time monitoring of traffic and cyber-physical infrastructure. All highway agency respondents to Saeed's survey[31], answered yes on this question. High-tech infrastructure is needed to real-time monitor the traffic flow. Technology failures must also be monitored quickly and all technology should be protected against cyber-attacks.

Lastly, incidents and roadworks change the situation for Connected AVs. Real time change should be clear for connected AVs, such as temporary signs and merged lanes. For this, readable and standardized signs must be established or smart digital roadside communications must replace static facilities[29].

Geometric design

Geometric design is understood here to mean: Othman [13] investigated the impact of AVs on various elements of physical infrastructure. Among others, he analyzed the impact of AVs on geometric design, translated into stop sight distance (SSD), pass sight distance (DSD) and the design of horizontal and vertical curves. It is concluded that compared to driver behavior, AVs have a more favorable impact on SSD and DSD. The explanation is that AVs react faster than a human driver, which decreases SSD and DSD. SSD is an important factor affecting the lateral clearance on horizontal curves. The introduction of AVs leads to a decrease in SSD and therefore a reduction in required lateral clearance. A width of 2.4 m is required for AVs. Obviously during the transition period to infrastructure for AVs, the road still needs to be designed for human drivers. But then simultaneously designed and constructed with capabilities to adapt for emerging vehicle technology. Infrastructure design will also need to take into account the fact that AVs advanced technology feels uncomfortable to road users. Consider rapid acceleration and shorter distances between cars [31].

What was stated above for horizontal curve length, also applies to vertical curve length, because the drivers' eye height and reaction time are the most important factors, and thus can be reduced for AVs. It is also found that curve radius and spiral curve length do not depend on characteristics of human drivers, so no changes required in that area [13]. This is in line with the findings of Saeed [31], who also says that almost no changes are expected in super elevation, radius of horizontal and gradient of vertical curves for new roads.

Another aspect is the influence of the road surface on braking distance. Taking this into account vehicle-to-vehicle communication (V2V) and vehicle-to-infrastructure (V2I), speeds can be adjusted, leading to adjusted breaking times and responsible stopping distances. Communication technology can also lead to the application of less skid-resistance materials for roads [29]. Because AV's have the ability to react uniformly and faster with the technology, platooning becomes possible. As a result freeway capacity can be increased with AVs in two ways: by increasing speed and by reducing headways to 0.5 sec reaction time of which AVs are capable of [31].

Other things that can be changed are bridge abutments, median barriers, crash walls, parapets, crest curves, sag curves together with overhead structures, distance/headway between the vehicles, intersection storage and turn bay lengths, and the intersection sight distance [31].

Pavement structure

AVs are expected to affect pavement performance through increases in roadway capacity, traffic speed and changes in wheel wander. Decrease in wheel wander and increase in lane capacity will lead to more wear and tear of the pavements. Also, the increase in number of kilometers traveled by vehicle, will cause faster deterioration of the pavement condition. In addition, due to their Lane-Keeping-systems (LKS), AVs are more likely to use some small part of the road, causing more rapid damage to the pavement. So, some parts need to be strengthened more often or the surface of the road surface (wearing course) needs to be made stiffer with deformation-resistance materials (e.g. asphalt)[31][32]. In short, that requires attention to pavement design. Another solution is to program the vehicles so that wheels sway a bit, which may reduce this deterioration, but then the lane width should not be reduced. The downside is also that this increases tire wear and also energy use. So, it is a cost-to-benefit analysis.

AVs can use real-time communication and electric vehicles can accelerate faster compared to gas combustion engine vehicles. As a result, it is possible to achieve shorter merging times and lengths even on busy highways and it is possible to allow steeper grades, shorter ramp terminals, shorter merge areas, shorter passages for turning and crossing vehicles and shorter queues and shorter turn bays [31].

It should also be taken into account that future roads could have a roll in charging cars. This could influence the decision for the type of pavement and type of construction [13][29].

Furthermore, surface water accumulation may cause connected AV systems become “paralyzed”. To avoid problems with these systems and avoid safety risks, higher priority should be given to the design and maintenance of drainage infrastructure [29]

Geotechnics

Lane-Keeping-systems (LKS) makes it possible to narrow carriage way, to create extra lanes based on the existing road width and tighter corners. Besides, in response of the needs of platooning, roads could be changed with reduced road gradients with more cuts and fills, embankments and tunnels to better and more efficiently control the speed of AVs [29][32].

Markings and signs

Another important factor that will affect the success of AVs is the traffic signs and road markings. These are important for locating, navigating and parking. The main system requirements are advanced signals, enhanced lane markings and compatible signs. Faded or poorly maintained markings and non-standard signs can make it difficult for AVs to recognize them. Therefore, maintenance, standardization of signs and, for example properly functioning street lighting are important [29][27].

The requirements needed for the development of infrastructure for AVs differ from the classical infrastructure. Accidents must be prevented by the improving of software that recognizes traffic signs. Traffic lights, priority signs, street signs, speed limit signs and other physical infrastructure will be redundant for AVs and should be replaced or added (during the transition period) by digital versions to instruct AVs. Until the digital versions are ready, the visibility, uniformity and consistency of road signage must be guaranteed. Lower variability in a number of parameters will be required and will increase the chance of adapting AVs. Optimal design and smart maintenance plans should also lower that variability in road signs [17][31][27]. During the transition phase it is also important that human drivers can respond to the behavior of AVs. It is important that this behavior can be recognized, expected or predicted by a human driver to avoid collisions [31].

Roadway Safety Devices

It dependents on the safety performance of AVs, whether guardrails, attenuators, cable median barrier and concrete barriers are still necessary. Furthermore, the need for shy line offsets to abutments and other fixed objects should be re-evaluated. But during the transition period, these devices are still needed. For mixed-use facilities, an exclusive lane for AVs could be designed. A barrier-protected operations could be considered, which may require a barrier-protected exclusive lane [31].

Speed limits

During the transition phase, 91% of Saeed's [31] highway agency respondents expect speed limits to remain the same. The reasons are that safety remains the top priority, fuel consumption is kept in control, expectations are maintained, and the limited cognitive and physical abilities of human drivers must be taken into account.

During the autonomous phase, 57% expect speed limits to increase because the human factor falls away, and AVs have a higher safety capability. In addition, efficiency and effectiveness increase and unpredictability decreases. However, this may not change in urban areas due to concerns of and about pedestrians and other vulnerable road users.

Hard Shoulders

The presence and width of hard shoulders may also be affected by the introduction of AVs. According to the questionnaire in the article of Saeed [31] 13% of the respondents think hard shoulder lanes need a greater width because of their function of refuge areas for, emergency responders, evacuation routes, human drivers, or because of software/hardware failures. 35% of respondents expect a decrease in width because AVs are expected to handle road conditions better and drive more accurately. Moreover, these hard shoulders were used for making calls, checking car functions or detecting car faults. Due to the fact that AVs no longer require the car user's attention and technology detects or even resolves possible system failures in a timely manner, these vehicles will stop much less than before.

39% think that hard shoulders will remain the same. This is because of safety and unforeseen reasons, such as parking, system breakdowns, additional pedestrian/bike traffic.

In addition to the questionnaire Saeed [31] also conducted a literature review in which he concluded that hard shoulders will still be needed in different locations, for breakdowns such as flat tires, system failures and emergency vehicles.

Parking

AVs has a lot of potential to reduce parking requirements. 65% of the respondents of highway agencies, surveyed on parking requirements in the article of Saeed [31], expect a decrease in overall parking needs. As part of Mobility as a Service (MaaS), AVs would run continuously and so no parking spaces are needed. Vehicle ownership will decrease, so fewer parking spaces are needed. Only centrally located parking spaces and loading/unloading zones are needed. 17% of respondents are unsure about the overall parking needs due to AV, because many people may not want to use public vehicles or wait for them to arrive. They want comforts and in a timely manner. 9% expect

an increase due to an increase in population. Finally, 9% of the respondents think it will stay the same, because cars still need to be parked. On the other hand, at airports, down-towns, event venues and residences parking demand may decrease, but there will still be parking demand [31]. On the other hand there could be an increase in other types of parking, for example for connected AVs that are used for the hire, near mobility hubs as train stations[27].
Auto-valet-parking can reduce future parking demand, connected AVs make shared cars more feasible requiring fewer cars and space. Moreover, closer parking is possible, because people are already outside the car and AVs are able to park more precisely, which is saving space. On the other hand, parking garages are not able to support self-parking and nowadays many parking garages are underground, where signals weak. According to experts, Bluetooth can solve the latter challenge. During the transition to autonomous driving, parking garages are needed, that have place for AVs and traditional cars [29] [13] [17].

Structural design of Bridges, tunnels and underpasses
Another effect of the benefits of AVs, could be that truck platoons (a convoy of autonomous driving trucks) are getting dangerous for old bridge constructions. This because of the bigger amount of weight on a smaller area. A solution could be that there should be a limited or minimum space between the trucks to lower the impact of these platoons. The result is that a minimum distance restriction is needed [13].
Bridges, tunnels and underpasses will be still needed to reduce conflicts between different traffic flows. Current bridge designs are not always ready for the "platooning" needs of heavy trucks. These designs should be updated to make them ready [29].

Safe harbour area
AVs can have implications for emergency refugee areas. Safe harbor areas will always be need. Therefore, additional spaces for this will always need to be reserved. Or the space left by reducing on-street parking can be used as safe harbor [13].
Safe harbor areas are essential for emergencies and for when cars reaches the exit of an automated operation area. These areas need to be considered in the future when meeting the needs for connected AVs. [29]

Service and charging stations
Service stations now have the main function of fueling cars. In the future more and more cars will be electric vehicles, which may also be able to be charged on the road. Until then, more electric chargers are expected at these service stations [29]. Infrastructure needs also be adapted for charging stations, taking into account location, impact of charging time, fleet size, waiting times and management of trip demand [17].

Traffic circle
There are two ways to consider the future of traffic circles. For now, traffic circles are seen as safer options, while for AVs intersections may be safer because of their predictability. On the other hand, traffic circles may be preferred because of their faster traffic handling and/or shorter delays and waiting times. This advantage will increase, when computer programmers succeed in improving the merging action on traffic circles [29].

Changes across arterial collectors and local roads for AV operations

The highway agencies were asked what it would take to implement AVs with regard to infrastructure. First of all, they say that an implementation of information technology across the country and all types of roads is needed. Uniformity of traffic control devices, more roadside infrastructure and real-time work zone traffic control updates are also needed.

The highway agencies also mentioned that it might be possible to do away with traffic signals and signs as well as smart infrastructure and new types of pavement markings. Furthermore, minor change to right-of-way configurations, narrower lanes and more access control, arterial will become more efficient and safer, reduction in number of controlled intersections and a lower urban travel demand is expected due to fewer vehicles for multiple passengers.
With regard to collector roadways, the respondents indicated a need for more bicycle and pedestrian facilities, more roadside infrastructure, smart infrastructure, new types of pavement markings, real-time work zone traffic control updates, installation of signalized intersection communication devices, more uniformity and consistency in roadway infrastructure installations and narrower lanes. Finally, for local roads, the agency expects a need for extensive signage and markings, which currently missing due to low-traffic-volume, and further also modernization of these roadways, such as installing roadside infrastructure, and information technology devices and traffic control devices[31].

Other Aspects

Finally, the article researched the readiness for AVs in the category cost of infrastructure. Adapting infrastructure for AVs will be time consuming and expensive. The infrastructure must guarantee uninterrupted, predictable, safe and efficient traffic flow. Modification of infrastructure is normally based on a 30-year planning horizon. The suggestion is to focus on sections of road rather than large-scale transformation.
Other cost items include costs for developing new methods, training of expert' personnel, building charging infrastructure and deploying equipment required for operation and maintenance of the infrastructure for the AV system [17].

According to the research of Saeed [31] five main types of infrastructure readiness are identified for both phases: enhanced maintenance (1), introduction of new infrastructure elements (2), removal of some of the existing elements (3), redistribution of some elements (4) and redesign of some elements (5). The following section discusses, the types of infrastructure readiness. Some of the previously identified factors are classified into one of the categories.

Enhanced maintenance

Pavement markings, pavement surfaces and road signs are now used by human drivers but are also important for AVs. More frequent and intensive maintenance is required. AVs are able to help with detecting poor stated pavements and road markings. While driving, the AVs can scan the infrastructure using their sensors and warn when maintenance is needed[31][32].

Introduction of new infrastructure elements

New lanes are needed for specific speeds or purposes when AV's are introduced. These lanes can be roads intended to be used as mixed roads or roads intended only for autonomous cars/trucks/buses.

Furthermore, high-tech infrastructure at intersections that can communicate with vehicles without traditional traffic light. Also required is an integrated network of cyber-physical infrastructure, supporting I2V, V2I, V2P and V2X. Both short-range and long-range communication systems must be in place. Finally, there must be infrastructure facilities for vehicle charging. This could be charging stations or charging lanes in the road[31].

Removal of some of the existing infrastructure elements
Infrastructure elements that AVs make obsolete include traffic signals, park-and-rides, and traffic lights. Due to the exchange of data about their speeds, directions and locations, vehicles could figure out their right-of-way and thus are traffic lights redundant. This applies to totally autonomous areas, but during the transition phase, these traffic lights are still needed. The same may be needed in rural areas, where traffic control systems do not exist[31].

Redistribution of some elements
Parking spaces could be reduced of changed to Pick-up and Drop-off zones[31].

Redesign of some elements
Some infrastructure elements may be modified or redesigned. Examples could be hard shoulders, guardrails and rumble strips. The physical dimensions of some infrastructure elements may become smaller, such as narrower lanes and smaller lateral clearance[31].

2.4.4 User Acceptance

Finally, the fourth and final main factor is "user acceptance"[17]. Implementation success depends on people's attitude toward AVs. The acceptance discussed consists of user acceptance, marketing and advertising, cost of AVs and trust. "Costumer acceptance" is hugely important to the success of the AV. Consumer mindsets will need to be understood, such as the knowledge and perceptions of different cultures. Thus, they must be able to understand the benefits of AVs, such as safety, efficiency, improved air quality and less congestion. Communication, education and training, can contribute to that acceptance. In addition, this means for the infrastructure that it should not only take into account the capabilities of the car, but also provide a sense of safety for the occupant and other road users. A safe and comfortable journey affects user acceptance and thus is relevant to the success of an introduction. It is also necessary for other road users, who are not using an AV, to provide education on how to behave around infrastructure where AVs move. The question to what extent the infrastructure can be purely focused for the AV applies here. This will have to be taken into account when designing the infrastructure.
"Marketing and advertising" can contribute to acceptance of AVs by familiarizing the user with the technology. The frequency of advertising plays a big role in this. In addition, different marketing strategies should be applied based on the different characteristics of the audience, as they have different acceptance levels. Cost, comfort and safety are important factors to consider.
The cost of AVs will also affect user acceptance. New technology is generally expensive. Expectations are that AVs will be expensive and not readily available to everyone to purchase. Uncertainty in production costs and necessary investments in scaling up production will drive up costs. And because fewer cars will be needed, the value per car is also likely to increase. On the other hand,

costs will decrease such as energy costs, insurance costs, trip length, travel times, congestion, safety, travel time reliability and maintenance costs.
Last, trust will play a crucial role in the acceptance of AVs. The user must feel that the technology will not harm them. Trust develops over time, with each stakeholder playing an important role in creating this trust. Education can play a role in convincing trust in the new traffic regime. In addition, providing the necessary control contributes to this trust.

2.5 Conclusions Theoretical Framework

In this chapter, literature on the definition of autonomous driving is discussed, followed by naming the different levels of autonomous driving, its potentials and challenges. Furthermore, it has discussed other factors that influence the feasibility of AVs in urban areas, which are: the current available technology of autonomous driving, laws and regulation, infrastructural factors and user acceptance.

There are several variations of automation levels, or degree of automation. This article focuses on the automation levels established by Miao. [8]The levels are: no driving automation (0), driver assistance (1), partial driving automation (2), conditional driving automation (3), high driving automation (4), full driving automation (5). For the levels 0 to 3 means that when automation fails, the vehicle still falls back on the driver for urgent events. For level 4 and 5, the fallback to an automated system.
Several advantages are cited in the literature regarding being able to implement AVs. These benefits are: increased safety (elimination of driver distractions, robots are never tired, faster reactions,), efficiency (reduced energy consumption, driving takes no attention from passenger, less parking spaces needed), mobility (multiple people able to go with AVs, such as elderly, people with disabilities and young people) and more sustainable, fewer cars needed, and they emit less.
Challenges have also been identified, including legal (liability,) user acceptance (trust in technology), complex system integration (robustness for sensor failure, a lot sensor are needed), dealing with uncertainty, dealing with non autonomous drivers (human drivers in traffic, cyclist and pedestrians), learning form previous mistakes, dealing with up scaling and verification and validation of AVs (how to test for unknown situations).

The literature identifies 4 factors, which affect the feasibility of AVs in urban areas. These are technology of autonomous driving, laws and regulation, infrastructural factors and user acceptance. The first factor, technology, is an important one in terms of feasibility. Technology can be simplified to a structure of entry, processing and output. This is where sensor technology plays a major role. Examples of sensors are: GPS, ultrasonic sensors, radar and camera systems. Sensors are important when it comes to recognizing objects, pedestrians, infrastructure and weather conditions. These sensors are crucial for safety, but are easily affected by bad weather, poor lighting, conditions or "non-line-of-sight obstacles (NLOS)," such as buildings, trees and hills. In addition, costs are high, given that many sensors are needed and must be properly maintained to remain in use. This makes it clear that sensor technology is still evolving. Research is now focusing on developing sensor systems and software for object recognition, object identification, object traction, object behavior prediction and other environmental factors. Machine learning and deep learning are expected to play a role in this development. Another technological aspect that may affect infrastructure and environmental factors is connectivity between vehicles and infrastructure. Examples include bridges, traffic lights or a VRUCW system. Much attention is paid to systems intended for communication between vehicles and other vehicles, infrastructure, pedestrians and the network, which allows the introduction of artificial intelligence (AI) technology. Furthermore, much attention is also paid to the so-called decision & control or the system that converts observations into alerts and reactions such as timely steering and braking. All these developments are important to make autonomous driving safe.

The second feasibility factor is laws and regulations. In relation to AVs, "policy and regulation," "liability," "privacy and cybersecurity" must be considered. Laws must avoid conflicts, and there must be consensus on the limits of liability and privacy.

The third feasibility factor is infrastructure. There is a big difference between infrastructure within built-up areas and on highways. For an AV it means that it has to take into account more infrastructure elements (curbs, crossings and traffic lights). Important elements identified in the literature that AVs have to take into account are weather conditions, greater variety of road users and lack of markings. In addition, adaptation and investment are needed in setting up and stabilizing communication systems (traffic lights, navigation, traffic jam recognition, V2X, V2V, V2I). This requires a wide, secure and stable network (connectivity). The use of AVs will require investments in infrastructure factors, such as: geometric design, pavement structure, geo-technics, markings and signs, roadway safety devices, speed limits, hard shoulders, parking, structural design of bridges, tunnels and underpasses, safe harbor areas, service and charging stations, traffic circles, changes across arterial collectors and local roads for AV operations, enhanced maintenance, introduction of new infrastructure elements and removal of existing infrastructure elements, redistribution of elements and redesign of elements. More sensors, well-maintained, legible and uniform marking and charging stations will be needed. Furthermore, it may lead to narrower roads, shorter entry lanes, shorter passages for turning and crossing vehicles, and steeper ramps. This should take into account, a higher degree of centralized wear and tear. AVs can be shorter, which can lead to more weight on bridges. This should be taken into account, or regulations should be in place (max distance between AVs on bridges). It is possible that the development of AVs combined with 'Mobility as a Service', which reduces car ownership, will lead to a decreasing need for parking. An uncertain factor is the effect of population growth. Loading and unloading zones will always remain necessary. To maintain road safety, no major changes are expected in the provision of safety measures such as guard rails, road verges and emergency lanes. Traffic circles and intersections will also remain as traffic intersections. Traditional gas stations will slowly disappear from the streets-cape and be more often outside the city, or be charged more locally, depending on charging times and supplies. So, AVs require the construction of smart digital infrastructure, new types of pavement markings, real-time work zone traffic control updates, installation of signalized intersection communication devices, greater uniformity and consistency in roadway infrastructure installations and narrower lanes. Signage and all types of markings will need to be expanded on local roads, where they are now lacking due to low traffic volumes. The same goes for installing roadside infrastructure and information technology and traffic control devices.

The last identified factor that affects the feasibility of AVs in urban areas is user acceptance. Consumer mindsets will have to be understood and vice versa the user will have to understand the benefits of AVs (such as safety, efficiency, improved air quality and less congestion). Communication, education, training and creating/maintaining trust are important, which can lead to acceptance. It is also important to teach the non-AV user how to use AVs.

3 Problem Statement

The introduction of Mercedes-Benz's "drive pilot" shows that technology is developing rapidly around autonomous driving. It shows that it can move fast and that there is a lot of potential in it. Several articles in the literature are optimistic about the benefits that autonomous driving will bring. However, the biggest challenge is yet to come. Namely, introducing AVs within built-up areas. There is a big difference between highways and driving in built-up areas. The introduction of AVs not only depend on the technological development itself. Other aspects besides the technology itself must also be taken into account. As technology for autonomous driving cars develops rapidly, it is important to prepare the environment for its introduction. The technology is being helped but also very dependent on infrastructural and environmental factors, such as laws and user acceptance. The introduction of autonomous driving might also lead to new risks and challenges. One such main issue is the dependency of an AV on the detection of infrastructure and other environmental factors, such as crosswalks, lines and curbs, but also cars, cyclists and pedestrians[17][26]. This means that the infrastructure plays an important role in the introduction of AV. There are still many questions about the feasibility of autonomous driving in built-up areas. Much attention in the literature is paid to the technology, but it will also be necessary to look at whether the infrastructure is ready for it. If this is not the case, it will require significant investment, which will cost time and money. This while the technology is already undergoing major development. What investments are needed or what needs to be researched? The question is to what extent stakeholders should invest in certain technology such as vehicle-to-infrastructure (V2I) systems. These include sensors in roads, traffic lights that send signals to AVs and bridges that indicate when they open. In addition to this type of infrastructure, a car still needs to be able to take into account various types of lines, road signs and other obstacles on or off the road including trees, pedestrian crossings and puddles of water[25]. Little is known about the feasibility of autonomous driving in urban areas in terms of infrastructure and environmental factors. What is known often lacks validated conclusions from different perspectives. This leads to the question of whether autonomous driving is possible from the perspective of safety in relation to infrastructure and environmental factors. If it is possible, there is also the question of whether the infrastructure is ready to allow autonomous driving safely. This may lead to delay and or postponement of autonomous driving within built-up areas. As a result, the potential benefits are not utilized or an introduction of autonomous driving may lead to problems that were preventable beforehand.

Most articles in the literature are positive about the potential of autonomous driving. In addition, the articles describe some challenges that AVs are facing. The challenges described in the articles are focusing on the limitations of the technology of AVs. What misses is a clear overview of the current state and challenge's of autonomous driving in urban areas in relation to infrastructure. Furthermore, a combined validation of these challenges and opportunities from different perspectives. As technology for autonomous driving cars develops rapidly, it is important to prepare the environment for its introduction. Change in vehicle or driving behavior and a decreased performance of the network, could impact the economic and environmental costs. Although there is already a lot known about the potential of autonomous driving. These days, research about the requirements for physical infrastructure is still in a fancy stage. Designers of new roads do most of the time still not take requirement for AVs into account. The main focus is on the digital infrastructure, while the physical infrastructure is still behind [13]. Furthermore, it is not known if infrastructural modifications are needed to ensure a successful introduction of autonomous AVs.

Since the 17th of may 2022, autonomous driving is allowed for some cars of Mercedes-Benz in Germany under certain conditions and restrictions [7]. The Mercedes-Benz DRIVE PILOT system is now only able to control speed, control distance and guides within the lane. Furthermore, is it able to route course, occurring route events and it can recognize, evaluate and anticipate on traffic signs. But more is needed when it comes to urban areas.

Saeed et al. [31] has researched the potential of autonomous driving. One part of the research is a questionnaire send to several stakeholders that are linked to AVs, which are technology developers, highway agencies and road users. One of the questions researched by Saeed et al. [31], is about locations that are likely for initial AV deployment. 53% of the technology developers answered that question with high-speed roads (freeways), followed by central business districts (18%) and restricted residential neighborhoods (12%). Rural roadways where chosen by 6%. Highway agencies answered on that question, high-speed roadways with 32% and business districts (24%). They argued that high-speed roadways that have controlled access, there are fewer chances of encounters and interactions compared to other road types. Besides, it is easier to measure the efficiency benefits on these types of roads and their greater degree of uniformity. They also suggest a geo-fence around areas where AVs may be allowed and where the infrastructure can support it. Other reasons where: the high-density environment offers better support and fewer changes for the fatal crashes that Uber's and Tesla's automated vehicles experienced (1). Such roads are the easiest for AVs to handle (2). There is limited access (3), AVs are easier to implement on these roads (4), high-speed limited access facilities are the most predictable environment for vehicles and are also the most logic place to switch to autonomous mode due to more long road trips (5). Finally, agencies are more likely to be able to maintain freeways in a condition that would support driverless vehicles (6).
There where also respondents who did chose for restricted residential neighborhoods as likely locations to start AV deployment. There reasons were that: these roads offer a more controlled lower speed environment where vehicles making repeated short-distance trips can be monitored (1), the investment is very valuable to village centers (2), the systems infrastructure (WIFI), will likely be more highly developed in urban areas. Residents in Public living and workers working in central districts are likely to gain more from AV operations, because they can for example benefit more from no parking fees, reduced congestion and improved safety (3).
Respondents also argue that rural roadways or better locations for the initial deployment of AVs, because these areas can be better used to test and evaluate the actual performance of AVs in real world roadway environment due to their low volumes open roads instead of more urbanized roads. Based on these answers, it can be concluded that there are different motivations for the different type of roads to start with the deployment of the AVs. In practice, more articles and literature about AVs are focused on the highway roads, where urbanized roads are left behind, especially if they are relation to infrastructure. This research wants to identify the factors that play a roll in the introduction of AVs in urbanized areas in the Netherlands, that differ from the factors that play a role on highway roads[31].

Problem statement:
Autonomous driving is a new technology, which has many difficulties and problems (such as detecting cyclists and recognizing roads) that must first be overcome to successfully introduce autonomous driving in the Netherlands.

4 Research Question

The purpose of this study is to gain insight into the feasibility of introducing autonomous driving within built-up areas in the Netherlands. This research aims to contribute by gathering information on factors that influence that feasibility. The focus is on the role of infrastructure and environmental factors. The first step is to identify infrastructural and environmental factors that influence or are influenced by autonomous driving. Next is to identify exactly what that influence is and in doing so, what the potential of autonomous driving is and what the challenges are. Ultimately, the goal is to uncover what the possibilities are, what challenges apply, what investments are needed and what still needs to be investigated to determine that feasibility. For this reason, the following question have been drawn up:

Research Question:
What influence do technology, laws and regulations, infrastructure and user acceptance have on the feasibility of autonomous driving in (Dutch) urban areas?

5 Research Approach

The purpose of this study is to provide insight into the feasibility of autonomous driving within built-up areas. The study focuses on infrastructural and environmental factors, which influence the success of autonomous driving within built-up areas. Ultimately, this research serves, to find out, what is needed, what potential challenges are and where further research needs to be done to determine feasibility. This chapter will circumscribe the approach which answers the research questions established in the previous chapter.
It was chosen to focus on the feasibility of autonomous driving within built-up areas in the Netherlands. This is because autonomous driving on highways is already allowed on some roads, but autonomous driving within built-up areas seems more challenging. The focus here is on built-up areas in the Netherlands, as the Netherlands scores high on KPMG's list, regarding openness and preparedness for AVs[5]. This research is curious about the additional obstacles, which still need to be overcome.
This research attempts to answer the research question using methodological triangulation, with the goal of collectively providing a broad-based answer. Methodological triangulation means that this research approaches the research question in three ways[33]. First, the theoretical framework provides a theoretical insight on what the literature has to say about autonomous cars in relation to infrastructure and environmental factors within built-up areas. In addition, interviews were conducted with experts, with the aim of identifying the feasibility of autonomous cars within built-up areas and answering what the challenges are. Finally, a document analysis has the purpose of collecting data to verify the claims made in the previous two parts.

5.1 Approach Theoretical Framework

The theoretical framework, searches literature about infrastructural factors in relation to autonomous driving in urban areas. It identifies the factors and its potential or challenge related to autonomous driving. In the theoretical framework, various terms were searched on literature databases and search banks such as "scholar.google.com". First research about understanding autonomous driving is done, to search for gaps in the literature. Search terms which are used to find literature about autonomous driving are: "autonomous driving in urban areas", "Autonomous driving technology" and "autonomous driving challenges". In addition, the research attempts to answer the question about what factors play a role and are on influence on urban roads on autonomous driving. Also challenges are searched and what could or should be done to fix them. It was investigated to what extent these components can actually influence and how much this is different from roads outside built-up areas. Research terms used for this purpose are: "autonomous vehicles and infrastructure", "autonomous vehicles on urban roads" and "readiness autonomous driving".
However, a literature review runs into the fact that it may fall short in practical validation. In addition, it approaches the research question, but does not directly answer the research question. For this reason, it also conducted an in-depth interview to identify further challenges. In addition, the document analysis contributes to validate the statements from the literature, by providing examples or counter-examples from practice for example.

5.2 Approach Expert Interview

To support on the literature, an expert analysis was done, with the aim of a deeper investigation of the research question. A good expert analysis requires a strong theoretical foundation, given by the theoretical framework, and a careful validation, the document analysis[34]. Expert interviews are by definition subjective and colored by the experts worldview, interests, employment status, and cognitive abilities. Other possible biases include: purposeful misrepresentation, unintentional misrepresentation, subjective interpretation, and lacking or insufficient memory/knowledge. Respondents may differ in their interpretation. Therefore, a single expert interview is of no value, multiple interviews or cross checks with other data streams increases the evidentiary value. This study accessed multiple respondents and cross checked the interviews using document analysis[35].

This research has interviewed 4 experts which helps to contribute their knowledge and experience to interpret the suitability of autonomous driving within built-up areas. An expert interview was conducted, which involved semi-structured interview methods. This means that pre-defined questions were prepared and follow-up questions were asked afterward. The three experts where asked of whom three senior consultant of an European engineering consultancy company, active in the fields of consulting engineering, environmental technology and architecture. Furthermore, one expert of an independent Dutch scientific research institute in the field of road safety. The three consultants are a "senior consultant save mobility", a "senior consultant planning transportation and mobility", a "Traffic data analyst". The title of the expert from the independent Dutch scientific research institute is "head of infrastructure and traffic debt". These experts where chosen due to their knowledge and experience in infrastructural design and mobility. Furthermore, there is a difference in expertise, which allows a different way of looking at autonomous driving. One more from the mobility side, the other more from infrastructural side. Also, the European engineering consultancy company has a lot of experience in developing roadways and situations The independent Dutch scientific research institute focuses on the safety of these traffic situations. These perspectives can contribute to filling the potential of autonomous driving within built-up areas in the Netherlands. The expert interviews attempted to answer the same questions as the literature review. However, the focus of the interviews was more on substantiating the effects and finding a possible approach/solution to the influence of the factors. The interviews were based on four pre-determined questions, which are:

1. What additional infrastructural factors (other than 50 and 60 km/h roads) are relevant and or will change or become more or less important when it comes to 30 km/h roads within built-up areas compared to the current 50/60 km/h roads outside built-up areas, as well as highways, that meet the requirements for autonomous driving?
2. Why are these infrastructure factors relevant and/or why do they change for 30 km/h roads, within built-up areas?
3. Do you have any recommendations for changing, or researching, infrastructural factors in the context of 30 km/h roads within built-up areas, focusing on safety?
4. What exactly are the conditions a road must meet in order to use the DRIVE PILOT system in Germany at this time?

Conducting interviews with experts has some limitations, such as selection bias. In addition, it is time consuming and the interviewer may affect the outcome, through influencing or interpreting the data.
The selection methods for finding experts for my interview is a combination of stratified sampling and convenience sampling[36]. The study approached different stakeholders to include multiple perspectives. Four groups were identified and approached (stratified sampling): infrastructure consultants and designers, infrastructure experts at the municipality, independent Dutch scientific research institute and experts of autonomous vehicle manufactures. Responses to interview requests were received from two of the four groups, with which interviews were eventually conducted. The infrastructure consultants also provided advice on who else to reach out to within the company, ultimately resulting in 3 consultants with different areas of expertise being interviewed. Despite approaching multiple groups, this research was based on who was available at the time, who has expertise in the field and was willing to do an interview (convenient sampling). A limitation of this research approach was that the experts consulted were not experts in the field of autonomous driving. This research has also tried to approach some experts of autonomous vehicle manufactures, but unfortunately, none of them responded. Because manufactures did not respond, information on technology development and its potential could not be taken into account. For this reason, this research misses the evaluation/input of the manufactures. The document analysis was used to partially fill in the that gap.

5.3 Approach Document Analysis

In conducting this study, the research question was approached from multiple perspectives. In the 'Theoretical Framework' chapter, literature research was conducted to find out what the science says about the feasibility of autonomous driving in built-up areas. Then, in the 'Expert Interviews' chapter, the perspective on that feasibility was explored by interviewing traffic and infrastructure experts. These experts are involved in designing the road infrastructure of the future. An expert from an independent Dutch scientific research institute in the field of traffic safety was also approached. This institute aims to optimize road safety. Finally, manufacturers of AVs were approached for the study. However, without response.

In addition to a literature review within the theoretical framework and an expertise interview, a document analysis was conducted. The document analysis aims to further validate the perspectives from this study. Validating means examining whether the outcomes of the literature review and expert interviews correspond to reality, as outlined by articles and documents consulted. The document analysis was conducted to find reports, (news) articles and other documents that confirmed, contradicted or complemented the theory and outcomes of the expert interviews. The validation focused on the following three categories: laws and regulations, manufacturers, and infrastructure.
The document analysis focusing on the laws and regulations category, aims to examine whether it is considered possible from a legal standpoint to allow AVs to access public roads, and whether the technology, used for driving AVs, has a chance of being allowed in public spaces. It also identifies aspects and challenges, which affect feasibility in this area. For the laws and regulations category, it looks at the status in terms of allowing AVs on the road. It also identifies governments' attitudes toward AVs and what, if any, obstacles need to be removed. This looked at governments worldwide

as well as the European Union and the Dutch government.

The document analysis focusing on the second category of manufacturers aims to include manufacturers' perspectives in this study and concerns the feasibility of autonomous cars within built-up areas. Documents from manufacturers were sought, highlighting their perspective. In addition, third-party documents on manufacturers in relation to AVs were sought with the goal of verifying statements made by manufacturers.

Finally, we zoomed in on the infrastructure category, searching for documents related to autonomous driving and infrastructure in the Netherlands. The aim of this was to gain insight into how the Dutch infrastructure is doing with regard to an introduction of AVs on Dutch roads and where the challenges lie. In addition, documents were searched for within this category, indicating the relationship between AVs and five specific infrastructure elements. The five specific infrastructure elements are: markings, bicycle lanes, traffic circles, road narrowing and intersections/crossings. These infrastructure elements were chosen based on the interviews and theoretical framework. This revealed that road markings are an important element for AVs, as they are not present everywhere, lack uniformity and can be challenging for recognition. In addition, it emerged that cyclists and pedestrians are a major challenge, with on-road bike lanes playing an important role. This is also typically Dutch and a major challenge. Furthermore, traffic circles were chosen since this is a typical infrastructure element within a built-up area and traffic circles are characterized by frequent contact moments between road users. Road narrowing was also chosen since this element is challenging and common within Dutch built-up areas. Finally, crossings/intersections were included, as this is an important and common element where a lot of interaction takes place.

For each category, documents were searched for via Google using targeted search terms. Documents were then chosen that appeared on the first or second result page and related to the research question. Also included were documents that resulted from a reference in a document or in the first or second result page. For the categories of laws and regulations, manufacturers and infrastructure, we chose to limit the number of documents to 10, 15 and 15 documents, respectively. Each subcategory is limited to between 2 and 5 documents. Below is a further explanation of how each category works.

Within the "laws and regulations" category, a distinction is made between the subcategories "laws and regulations worldwide", "laws and regulations Europe", "laws and regulations Netherlands". Search terms used for "laws and regulations worldwide" are "laws and regulations +autonomous +vehicles +AV +cars +driverless +vehicles +Urban +areas". Search terms used for "laws and regulations Europe" are "laws and regulations +autonomous +vehicles +AV +cars +driverless +vehicles +Urban +areas Europe". Search terms used for laws and regulations Netherlands are "laws and regulations +autonomous +vehicles +AV +cars +driverless +vehicles +Urban +areas Netherlands."

In the "manufacturers" category, the focus is on the manufacturer's perspective regarding the feasibility of autonomous cars in urban areas and the reliability of autonomous car technology. Four manufacturer websites were searched, namely Mercedes, Tesla, General Motors and Waymo [4][7]. These manufacturers were chosen since these four companies are at the forefront of autonomous car development and already have cars on the road. For example, Mercedes has already received permission to test its autopilot at automation level 3 in Europe. Tesla owns advanced technology and has the largest fleet of AVs and data. General Motors is one of the largest car suppliers in the world and has permission to drive self-driving cars in California. Waymo, which is part of Alphabet (Google), is in the advanced development stage of autonomous cars and already has a self-driving cab service running in Phoenix. Search terms used for this are: "Site:www.mercedes.com driverless OR autonomous cars OR vehicles OR driving infrastructure OR urban", "Site:www.tesla.com driverless OR autonomous cars OR vehicles OR driving infrastructure OR urban", "Site:www.gp.com driverless OR autonomous cars OR vehicles OR driving infrastructure OR urban" and "Site:www.waymo.com driverless OR autonomous cars OR vehicles OR driving infrastructure OR urban". This included further clicking around the website. In addition to researching their website, we also Googled manufacturers in general, with the goal of including their perspective regarding feasibility, with the manufacturers themselves not being the source. The search term for this was "Manufacturers about feasibility Autonomous OR driverless cars OR vehicles in urban areas."

The document analysis focused on the third category "infrastructuur," related to the introduction of AVs, helps to gain insight into the extent to which theory about AVs and infrastructure corresponds to reality. The purpose of the analysis within this category is to examine documents on AVs and infrastructure elements or gather insights that help validate the theory or not. First, we searched for infrastructure related to AVs in the Netherlands in general. For this, the search term "Zelfrijdende auto in Nederland Infrastructuur" was used. In addition, a search term for each type of infrastructure was used in combination with "AVs in the Netherlands" using Dutch search terms. "Zelfrijdende auto Nederland markering", "Zelfrijdende auto Nederland fietspaden", "Zelfrijdende auto Nederland rotondes", "Zelfrijdende auto Nederland wegversmalling" and "Zelfrijdende auto Nederland kruispunt OR oversteekplaats".

5.4 Biases

This research aims to provide the most objective and scientifically valid answer to the research question. The following is an overview of the possible biases, which may be applicable to this research. It is also explained how the research dealt with them. The research started with a theoretical framework, looking at what the literature says about the research question. Here, one possible bias is confirmation bias, which means that the researcher tends to look for information that supports his/her existing beliefs while ignoring information that contradicts them. This is one of the reasons to also approach experts for an interview from different areas of expertise to get a broader perspective on the research question. However, conducting interviews is also prone to biases. To this end, several biases have been identified that this study has tried to take into account.
The first bias is sampling bias (sampling bias or ascertainment bias). This occurs when your sample is selected in such a way that it is not representative of the population. An attempt was made within this study to approach different stakeholders, who have different backgrounds, expertise or perspectives on Autonomous Driving. A second bias is undercoverage bias, which accounts for under-representation of a certain segment in the population. The purpose of this document analysis is to validate whether statements in the literature and in the interviews match reality, so that these conclusions are substantiated more broadly than just from the interviewee or a found article.

The following biases relate to the conduct of interviews. Biases taken into account are interviewer bias, response bias, participation bias, social probability bias, question order bias and undercoverage bias. Participation bias, takes into account participants who do not respond to a request to cooperate in a study or withdraw. In this case, this came up with manufacturers. Requests for interviews were not responded to. This study attempted to include this perspective through document analysis.

During the interview itself, there may be interview bias. Interviewer bias means that the interviewer influences the research, by the way of asking questions and or responding to answers. In this study, the questions were sent in advance and in addition, all interviews were conducted online to give them room to think about answers in advance. In addition, the interviewer has no connection to the research topic other than to research it. The interviewer has no interest in influencing the research in any particular direction. Furthermore, the question order and response bias was taken into account by starting with open-ended questions and then specifically asking questions later. This is to prevent respondents from being influenced, by the previous question.

Another possible bias that may affect this study and relates to the document analysis is selection bias. This stems from the fact that the researcher is responsible for selecting the documents. In addition, the result depends on the Google search algorithm and the time of research. For example, there will be other articles in the news at other times. The triangulation of studies aimed to minimize the risks of biases to ensure the validity and reliability of the findings.

6 Expert Interviews

For this study, 4 experts were approached, who have knowledge and experience in the field of infrastructure and mobility. They were asked to identify factors that are influenced by the possible introduction of AVs. They were also asked what effect AVs would have on these factors. In addition, they were also asked to identify what are infrastructural requirements and what is recommended for a successful introduction of AVs in built-up areas in the Netherlands. Chapter 8.1 discusses the identified infrastructural factors. Chapter 8.2, discusses the identified challenges and recommendations.

6.1 Identified Difference Infrastructure Factors Highways and Urban Roads

Four experts were asked for their views on the consequences of autonomous driving on infrastructure. In the discussion with the experts, questions were asked about infrastructure factors affecting the feasibility of autonomous driving within built-up areas. It was specifically asked what, infrastructure around roads within built-up areas, should be taken into account, compared to highways. Factors that emerged are discussed in this section.

Road Function and Road Users

The first difference identified by the experts and considered to be an important difference are the road function and the type of road user. In the Netherlands, each road is divided into a traffic function and a residential function. There are roads that have only a traffic function, only a residential function or a combination of both. With a traffic function, the road should only be used for mobility and transport. With a residential function, roads serve only as a function where people live, store, recreate, etc. In addition, there is a combination of both functions where a lower speed is desired, considering safety and the many road users. Highways only have a traffic function. It is not allowed to stay here. Within urban areas, roads with a residential function or a combination of both are much more common. Therefore there are many differences between the two roads.
The traffic function is determined by how the road is to be used. One of the most important factors, seen in the context of safety, is the type of road user. On highways, only motorized vehicles are allowed. These are mainly cars, trucks, buses and motorcycles. Within built-up areas there is a greater variety of road users. Here, road users are allowed, who are a lot more vulnerable, such as pedestrians, cyclists, scooters, etc. But also stints and other vehicles, which may be less easy for AVs to recognize. In addition to vulnerability, road users also differ in range in terms of speed. Cars can cover distances much faster than pedestrians and cyclists. That is why, separate bike lanes and sidewalks have also been constructed in inner cities, with the goal of distributing the different types of road users across the space to promote safety.

Bike Lanes

On 80 km/h roads, bike lanes are required to be separated. The car always has the right of way here. On 50/60 km/h non-urban roads, there may be a bike lane on the road or bicycles are allowed on roads. Otherwise, the car almost always has the right of way. On 50 km/h roads within inside built-up areas, sometimes cars have the right of way and sometimes cyclists, for example at crossings. The policy is to give more space for cyclists and pedestrians. As a result the traffic function is increasingly changing to a residential function, where cyclists and pedestrians have priority. This also results in the maximum speeds of roads changing from 50 to 30 km/hour. On 30 km/h roads, cyclists and pedestrians almost always have the right of way. The trend is that these types of roads are increasingly changing from a traffic function to a residential function, which means that the car is more often a guest. Within the built-up area it varies quite a bit what exactly is the place for cyclists. There may or may not be separate bicycle paths and/or bicycle lanes. There are bike lanes where cars are allowed and where cars are not allowed. In addition, the markings here are not necessarily consistent. This lacks uniformity, which is already reasonably present, but which, is often deviated from in practice. This also means a lot of ambiguity for AVs; for example, it is difficult to determine where AVs should or may drive and what decisions should be made by AVs. It also depends on the type of sensors what exactly it means for the safety of a cyclist.

Highways and direction of travel

Unlike urban roads, highways are constructed with separated lanes in one direction of travel. Most highways also have a guardrail between the lanes with a different direction of travel. In some cases, there is only a shoulder. On county roads, where compared to built-up areas, high speeds are also allowed, the lanes are separated by a narrow intermediate lane or lines.

"You have oncoming traffic within built-up areas, which you don't have on highways."

But all roads have their own separate carriageways. In contrast, on urban roads, the driving directions are often not separated by intermediate lanes or lines, or in other words, there are many roads with opposite driving directions. Motorists, after obtaining their driving license, can more easily move safely on these latter roads and, anticipating, assess traffic situations. AVs will have to learn to deal with this. On the other hand, it can be expected, that AVs can be programmed in such a way, that no intermediate verges are needed for safe forward movement on roads with two-way traffic. Not even if two-way roads within built-up areas differ in shape and size. That said, it is a very big challenge to program AVs in such a way that they can safely propel within built-up areas.

Intersections/Crossings

A greater variety of road users can be found on downtown roads than on highways outside of built-up areas. Because of this greater variation, within built-up areas there are many more intersections, traffic circles and crosswalks, such as pedestrian crossings and bicycle crossings.
On highways, there are no level intersections or crossings. There, one finds on- and off-ramps, allowing neat merging via lanes or leaving the main road. In general, for within urban areas, the more urbanized area, the more intersections, traffic circles and cross walks there are. This brings many challenges. Within built-up areas, there are many places where crossing is allowed on 50 km/h roads. On 30-km/h roads, crossing is allowed everywhere. Therefore, it is difficult for an AV to estimate when and where road users are allowed to cross. In addition, within built-up areas, there are many different types of road users, such as pedestrians, cyclists and motorists, which must be recognized by an AV. Especially also in combination with the many different objects, which are not road users or part of the road infrastructure. Thus, it is difficult for an AV to estimate what kind of road user is detected and what the intention of this person is. In addition, in built-up areas there are also many more side roads, where various types of road users can come from. And traffic rules also play an important role. Think of the different priority rules at equivalent intersections

and priority roads. This is trickier for AVs than for humans to consider and anticipate.

Speed & Speed Reduction Measures

Speed is another relevant factor discussed in this area, but which is not necessarily an infrastructure factor. A big difference between highways and built-up areas is already the speed that can be driven and the variety of speed that can be driven. On highways, people generally drive faster than 70 km/h, where within built-up areas they drive slower than 70 km/h. Based on the total length of roads within built-up areas, about 70% of roads within built-up areas have a 30 km/h speed limit. 50 km/h roads are about 25% of the length within built-up areas. The remaining 5% of the roads are either 70 or 15 km/h. Furthermore, the variety of speed limits is also much greater within built-up areas, than on highways. Highways do have a more consistent speed limits and the difference between vehicle's speed is smaller. Another difference between highways and built-up areas are speed reduction measures. To keep road users to the speed limit, several measures have been taken to influence road user behavior to adhere to it. One of these is the type of road based on the desired speed.

Speed reduction measures are those intended to influence the speed of vehicles to drive more slowly. These measures exist mainly on 30km/h roads. In addition to the previously mentioned clinker paving. There are also other measures:

- Speed humps: Speed humps are necessary to keep vehicles at the speed limit. With only AVs, these are no longer needed, since the car will adhere to them. In the transition period, they will still be needed, for non-autonomous vehicles. Until then, AVs, should recognize them and not see them as obstacles requiring stopping.
- Road Blocks.
- Chicanes.

On 50 and 60 km/h roads outside built-up areas and highways, there are hardly any such measures. Only camera's and trajectory speed control systems. So here an AV does not have to take objects, meant as speed reduction measures, into account either. For instance, speed reduction measures are necessary to keep vehicles at the speed limit. For AVs, these and other obstacles will no longer be needed, because these cars will stick to the speed. In the transition period, they will still be needed for non-autonomous vehicles. Until after the transition, AVs should recognize the measures and not see them as obstacles that necessitate stopping.

Type of road

The speed limit affects the type of road. For example, the width on highways is wider than on roads in built-up areas. The rule of thumb is that the lower the speed the narrower the roads are. Furthermore, the type of road surface is also different. Whereas highways all have different variants of asphalt, urban roads differ a lot more. In addition to asphalt, there are also clinkers and other types of road surface. Within built-up areas there are many different variants, including bicycle lanes, provincial roads, access roads, and so on. All different from each other. Which affects the recognition of roads from the AVs. The width of the road and the type of road surface such as clinker have the function of acting as speed inhibitors. This is a difference, which autonomous driving cars will have to take into account.

Other obstacles

All objects found near highways are designed specifically for these roads. Those objects are often designed to be collision-friendly. This means they are built to minimize the impact of a collision. Moreover, on highways, the number of objects is also minimized. This is in contrast to in built-up areas, where many more objects can be found. On highways it is still doable for AVs to learn the objects, but within built-up areas this is almost impossible because of the wide variety of collision-prone objects. For example, within built-up areas you will find different types of bollards, trees, lampposts, etc. along the road. These objects sometimes make it difficult for cameras to recognize danger. For example, if someone stands behind a tree, advertising signs or bike racks and tries to enter the road, etc.
Weather conditions such as storms can also affect road obstacles such as reduced visibility due to rain, snow and fallen leaves,etc.

"People are best at handling abnormal situations."

Humans can recognize and deal with these more easily than AVs. Due to the greater number of obstacles on roads in built-up areas, these influences are greater than on highways, the none disadvantageous to AVs in built-up areas.

Road marking

A important difference between highways and urban roads is the markings. On highways, markings are standardized (to a large extent internationally), well maintained and clear. On urban roads this is much less the case. For example, on 30 km/h roads there is little to no marking. The separation of road and other area here is marked in many different ways. This makes it a tricky area for AVs. Marking is possible, but apart from the costs and extra work, it is also not desirable to apply markings on these types of roads. After all, you don't want to suggest that you are the only one in the lane. Marking can invite you to drive faster, when in fact 30 km/h is driven on these roads because other, more vulnerable, road users are also allowed. Marking should also be well maintained and should not be temporary road markings all the time. Also, the markings must be clearly visible under all condition. Furthermore, there are temporary markings due to road works, for example, which AVs may have to deal with. Should there be temporary road markings, it is also very important to remove them properly so that there can be no confusion in a normal situation. The same goes for sidewalks. Within built-up areas, there are many variations of sidewalks. Curbsides are used as separations from the road section, a form of marking. But sidewalks are also crossed when leaving certain residential streets (residential areas) and the like. This is not always clearly marked and standardized. Which can be a big challenge for AVs. For AVs, one possible option is for roads to be marked online. However, this is unclear to other road users and therefore dangerous. It also does not solve everything, such as crossing sidewalks.

Traffic Signs

Traffic signs are often well and clearly placed on highways. In addition, there are only a limited number of types of traffic signs on highways. Within built-up areas, that variety is much greater. And those signs are much harder to see, because they are often behind objects or otherwise hidden. The question is whether AVs are capable of driving safely without road signs, or whether it necessary to identify and recognize all road signs. In any case road signs will continue to be needed as long as vehicles are driven by humans. It is also important that during the transition period, when both

AVs and human-driven vehicles are allowed to drive, the signs are the same. This applies to all traffic rules, by the way.

Parking spaces

Another difference between highways and urban roads is the ability to park. In inner cities, there are many parking spaces along the road, all of which are also marked and laid out differently. On highways it is not possible to park next to the road. Only in cases of emergency is there a possibility to stop, but these are not parking spaces. Within built-up areas, parking spaces are very different, so there is congestion parking, they are at right angles to the road, or at an angle to the road. Furthermore, the markings are very different and not always very visible. For example, sometimes you may and sometimes you may not park on the sidewalk. The same goes for on the road or differs the pavement. Also, sometimes parking is supposed to be half on the sidewalk. On 50 km/h and higher roads you'd rather not have parking spaces, because it is dangerous when parking or pulling away. For AVs, this is difficult to discern for every situation. In addition, AVs do not know how to properly assess whether a car is parked or participating in traffic. Ideally, each parking space should be marked in the same way.

Public transportation: Trams, buses, subways, railroad crossings

Public transportation also affects infrastructure and road safety. On highways, buses travel, sometimes in their own bus lane, but otherwise participate in traffic like any other road user. Within built-up areas, however, there are also trams, subways and railroad crossings that cars have to deal with. Mainly stops and tracks and railroad crossings need to be recognized by AVs. Also, trams, subways and trains have a different driving style, so they need to be taken into account in some way.

Bridges and Tunnels

For tunnels and bridges, in general means that the road surface and markings here are the same on the bridge as the part just before or after the bridge. It doesn't mean that it can differ as well in some situations. A bridge is also able to open up, so AVs should and can deal with a situation like that. Then tunnels, for tunnels it is important to deal with the possibility that a connection can be disrupted. However, the advantage is that AVs can communicate in advance with infrastructure such as bridges and tunnels.

Light

Light can affect road situations, it can blind cameras or give a distorted view of the actual road situation, such as markings etc. This applies to highways as well as roads in urban areas.

Residential

When discussing infrastructure factors, residential areas have been frequently considered, but not yet explicitly. This is important, however, because residential areas differ most from highways.

"It gets harder and harder for AVs the deeper you get into built-up areas."

In residential areas there are many obstacles, often no various markings, many different and vulnerable road users, and parking and play are allowed everywhere. AVs have to deal with poorly marked frames and many different situations, including children playing and pets. It is also often maze-like and anyone can walk and drive anywhere. This presents a major challenge for AVs. In terms of recognition by AVs of the various infrastructure factors in the residential neighborhood, it is desirable to strive for as much uniformity as possible in the Netherlands / Europe. As for traffic signs and road markings.

6.2 Identified Challenges & Recommendations from Experts

This subsections 8.2.1 and 8.2.2 discusses challenges, recommendations and expected infrastructural requirements needed, based on the interviews with the experts. The general expectation in the field of autonomous driving in the inner city is that it will be a major challenge to switch to fully autonomous driving everywhere.
According to the experts, the more interaction with various vulnerable road users, the more difficult it becomes to successfully introduce autonomous driving. The expectation is that certain area access roads, or main roads within built-up areas, may still be suitable for autonomous driving. The deeper you go into residential areas and/or the center of a populated area, the greater the challenge for autonomous driving. According to experts, there are certain challenges, which make it more difficult.

6.2.1 Identified Challenges

The large number of differences in infrastructure within built-up areas compared to highways leads to greater challenges in implementing AVs within built-up areas. This is influenced by the factors identified above. In addition to the differences, the expert interviews also discussed the challenges for AVs within built-up areas were discussed. This section describes these challenges.

<u>Vulnerable and different road users</u>
The biggest challenge mentioned by every expert was driving an AV safely on roads where there are many different road users. Mentioned were: pedestrians, cyclists, children playing, pets, scooters, stints and all other forms of road users. AVs must not only recognize them but also be able to assess them in behavior and intent.

"If you build safety margins into an AV, you are almost constantly at a standstill in crowded areas as an AV."

Here, roads that have more of a residential function pose the biggest challenge. Shopping streets are incredibly crowded with people and crossings are made in many places. AVs have limited ability to deal with this. People are better at estimating and enforcing a route, including through eye contact. AVs cannot do this and then, for example, tend to remain stationary and "neatly" wait until the road is clear. In residential areas, the variety of objects on and along the road is a great challenge in combination with playing children and the like.

"The more tunnels and segregated roads you have, the easier it is for AVs."

Recognizing potential danger is more challenging here than on highways, where a limited number of factors come into play. The advice is: invest in separate roads as much as possible, where vulnerable and non-autonomous vehicles are separated from AVs. Consider separate bike lanes. Main and closure roads are suitable for this, but the further you get into residential areas, the more difficult it is to separate vulnerable road users from AVs.

Standardizing roads

Furthermore, non-standardized roads are a challenge. The more you get into residential areas and within cities, the less standardized the roads are. This in terms of markings, road surface, driving directions, signs, parking, etc. For AVs, a standardized road makes it easier to drive on. Investing in that standardization is pricey, time-consuming and labor-intensive, but not impossible. All roads are now set up for an average depreciation period of 30 years. So, fully standardizing roads, without bringing forward the renewal of roads, will take 30 years. It is also the questionable whether it is possible to cast every road in a standardized mold. Roads serve different purposes. There is also a difference in architecture and there are different (functional) wishes for each road, given the traffic situation. Per road will have to be considered whether standardization is appropriate.

Transition period

Another challenge, the experts say, is the potential transition period, during which AVs will drive alongside human-driven vehicles. Thus, the AVs must have the same information as the human-driven vehicles. If the information differs, for example, due to differences in information about traffic signs, road lines, traffic lights, etc., this could lead to dangerous situations. Further research into a transition period, where AVs and human-driven cars drive simultaneously, can tell more about dangers and challenges and their feasibility. For example, by looking at people's driving behavior when they encounter AVs on the road. Or research into what markings and road signs, work well for both AVs and humans.

Support

There also needs to be public support. Traffic engineers are not in a position to dictate to road users. Whether AVs are actually introduced depends on public support. The population must agree to AVs being allowed on the roads and a possible ban on non-autonomous driving. For example, how will they react to an accident, involving an AV. To what extent will they accept that control of vehicles on a road is no longer entirely in the hands of a person, but a computer.

Liability

"Who is responsible in an accident?"

Another challenge is to establish liability in such a way that it is clear to everyone, such as road users, insurers, developers, drivers, etc. This avoids big surprises and ambiguities.

6.2.2 Recommendations

Based on these challenges, recommendations were also made by the experts. If autonomous driving is to be introduced within built-up areas, certain things will have to change or be invested in to promote safety and successful introduction.

Separate as many road users as possible

Separation of road users will prevent accidents because there are fewer interactions with vulnerable road users. This means that pedestrians, cyclists, should not be allowed on roads where autonomous driving is allowed. Suitable roads for autonomous driving are roads with separate bike lanes, private lanes, no parking spaces, directional separations and no crosswalks. Exception can be made for intersections with traffic lights, that are at a reasonable distances from each other.

There should also be support for such vehicles/systems. The selection of roads for autonomous driving should be based on the number of interactions with traffic and the degree to which autonomous traffic is separated from other traffic.

Standardized marking and roads.

Auto highways on which autonomous driving is allowed have high safety requirements. Road design for these roads is simpler than for roads within built-up areas, because the great diversity of road users allows for much variation in road design. Nevertheless, municipalities should also meet the strict standard requirements for roads intended for autonomous driving. This would then have to be standardized. This also applies to temporary situations, such as road works.

No parking spaces along the road

Parked cars can cause confusion for AVs. Parking spaces are not always clearly marked and far from standardized.

> *"It seems difficult for AVs to be able to recognize parking spaces within built-up areas. It's indicated with markings, different color brick, with a sign or just on the street."*

Recognizing parking spaces and parked cars is a challenge when AVs have to drive past them close by. The advantage of AVs, however, is that far fewer parking spaces will be needed if these cars can drive themselves to a parking space and if shared transportation becomes more prevalent. Stationary cars in parking spaces will then be less needed. Investment in removing and modifying this infrastructure is desirable.

Reduced speed on mixed-use roads

For roads where the previously mentioned requirements are not possible, such as segregated road users, one-way traffic, etc., another proposal emerged during the interviews with the experts. The proposal is that AVs should maintain a low speed limit, which should reduce accidents and their severity. If AVs maintain a speed limit of, say, 10 or 15 km/h on roads with mixed road users, this might reduce the number of serious accidents. This enables autonomous driving within areas with many types of road users in built-up areas.

A vehicle can then be stopped within seconds, and an accident at such a speed results in fewer serious injuries. Research into this can tell more about whether these claims are actually true and test their feasibility.

Mobility hubs

The complexity of autonomous driving for yard roads and city center roads, could also lead to a ban on autonomous driving on these roads. An alternative to this could be mobility hubs. Mobility hubs are hubs in neighborhoods, from which autonomous driving can take place. This means that, for example, a hub should be available no more than a five minute walk from every home, of where autonomous driving is allowed and from which self-driving cars are allowed. This brings challenges for people with limited or poor mobility, for relocation, mechanics, etc. Other transport, driven by humans can then serve as an alternative to this on these roads. Research on mobility hubs and their feasibility can be interesting to help consider this alternative.

> *"In Utrecht, neighborhoods are already emerging where you don't park your car in the street, but at a central point. This is called mobility hubs. There will still be closed streets for emergency services, package deliverers and emergency services."*

6.3 Conclusions Expert Interviews

Because of the differences in functionality, the experiences currently gained from testing AVs on test tracks and highways cannot be adopted one-to-one for urban roads. Highways have a traffic function; urban roads have a residential function or a combination of both. Depending on the function, the type of road user, speed limits and road infrastructure design are determined. The fewer types of road users use roads, the less the variation in maximum speeds of those road users and the more "simple" and uniform roads can be constructed, making the roads more suitable for AVs. As a result, autonomous driving can be expected to be allowed on highways, rather than urban roads. The challenges on urban roads are numerous. Within urban areas, autonomous driving will have to take into account a wide variety of road users, who often use each other's roads and encounter each other at crossings, etc. This makes it very important to be able to detect the intentions of the road user. Something that is difficult to program. Within built-up areas one finds a large variety of speed limits (30 - 50 km/h), types of road surface (asphalt, bricks, tiles), (temporary) markings and traffic signs, speed limiting infrastructure (speed humps, road blocks, chicanes), parking locations (along or perpendicular to the road, partly on the sidewalk, blue zones, etc.) and road lighting. Residential areas (neighborhoods) in particular are characterized by a wide variety of traffic participants, including children playing and people walking their dogs, and types of road obstacles (bollards, disabled parking, electric charging).

All this makes the programming of AVs very complicated. Difficult aspects to program are the (unpredictable) behavior of road users and the wide variety of infrastructural features of roads, squares, artworks, markings, etc.

But there is a lot involved in this. Without being exhaustive now, first of all, public support for autonomous driving will have to be increased. This will require gaining confidence in autonomous driving technology. This requires a lot of time. A time period that can be classified as a transition period, during which roads, squares, etc., both outside and inside built-up areas, can be designated to make them suitable for AVs. The more in doing so, the more efforts are made to standardize these elements, the easier the programming of AVs will be.

Criteria will have to be established for the designation and adaptation of infrastructure. These include (being able to) standardize roads and the like with separate use for different types of road users, of markings and signs, of the implementation of functions such as parking, crossings and mobility hubs in residential areas, but also the application of unambiguous, uniform traffic rules.

Roads (mixed-use roads) that do not qualify for standardization within built-up areas should not be opened to autonomous driving for safety reasons. One way to make autonomous driving possible on these roads anyway could be by setting a maximum speed of, say, 15 km/h. This speed minimizes

the chance of accidents and the severity of a possible accident. The effects of such a solution should be further investigated.
Furthermore, the unambiguous and uniform application of traffic rules (think of priority rules on traffic circles) requires good coordination between municipalities.
Given the current depreciation period for infrastructure, a transition period of at least 30 years must be taken into account. During that time, provisions must be made that allow for a gradual transition from the current human-based driving to autonomous driving.

7 Document Analysis

To validate the interviews and theory in the literature, document analysis was done. The validation was done by searching documents from multiple perspectives. This focused on three main categories, namely ”laws and regulations”, ”manufacturers”, and ”infrastructure.” This chapter provides the overview of sources consulted and discusses the conclusions from the document analysis for each category.
In table 1 an overview of all the documents analyzed is given.

Table 1: Document list

Category	Search term	Index	Title	Reference
Laws and regulation worldwide	**laws and regulation +autonomous +vehicles +AV +cars +driverless +vehicles +Urban +areas**	1	**New rules to improve road safety and enable fully driverless vehicles in the EU**	[37]
		2	**UNECE is driving progress on Autonomous Vehicles**	[38]
		3	**Autonomous vehicles: Driving regulatory and liability challenges**	[39]
Laws and regulation Europe	**laws and regulation +autonomous +vehicles +AV +cars +driverless +vehicles Urban areas Europe**	4	**EU Releases Proposed Automated Driving Systems Legislation**	[40]
		5	**Autonomous vehicles: cross jurisdictional regulatory perspectives update**	[41]
		6	**Key Trends that Distinguish North America and Europe in the Autonomous Vehicle Evolution**	[42]
Laws and regulation Nehterlands	**laws and regulation +autonomous +vehicles +AV +cars +driverless +vehicles Urban areas Netherlands OR Nederland**	7	**Self-Driving Vehicles a Cat and Mouse Game between Innovation and Legislation**	[43]
		8	**Global Survey of Autonomous Vehicle Regulations**	[44]
		9	**Self-driving vehicles**	[45]

		10	**Netherlands: Legislation to Allow More Testing of Driverless Vehicles**	[46]
Manufacturer Mercedez Benz	**Site: mercedes.com driverless OR autonomous cars OR vehicles OR driving infrastructure OR urban**	11	**Automated driving in urban traffic Autonomous and safe**	[47]
		12	**The front runner in automated driving and safety technologies**	[48]
		13	**Legal Framework Automated and Autonomous Driving**	[49]
Manufacturer Tesla	**Site: tesla.com driverless OR autonomous cars OR vehicles OR driving**	14	**Future of Driving**	[50]
		15	**Autopilot and Full Self-Driving Capability**	[51]
Manufacturer General Motors	**Site:www.gm.com driverless OR autonomous cars OR vehicles infrastructure OR urban**	16	**2018 Self Driving Safety Report**	[52]
		17	**Path to Autonomous**	[53]

Manufacturer Waymo/ Google	**Site: www.waymo.com driverless OR autonomous cars OR vehicles infrastructure OR urban**	18	**The World's Most Experienced Driver**	[54]
		19	**Waymo Driver**	[55]
		20	**Waymo Safety Report**	[56]
Manufacturer News	**Manufacturers about feasibility Autonomous OR driverless cars OR vehicles in urban areas**	21	**Where the billions spent on autonomous vehicles by U.S. and Chinese giants is heading**	[57]
		22	**Driverless buses are arriving soon in these 3 European cities**	[58]
		23	**Computer Driven Autos Still Years Away Despite Massive Investment**	[59]
		24	**How autonomous-vehicle companies and cities have learned to work together**	[60]
		25	**GM's Self-Driving Expansion Faces Challenges in San Francisco**	[61]
Infrastructure Netherlands	**Zelfrijdende auto in Nederland infrastructuur**	26	**Effecten op de infrastructuur**	[62]
		27	**Zelfrijdende voertuigen**	[63]

		28	**Nederland 'best voorbereid' op autonome auto's, fietsers maken komst lastig**	[64]
		29	**2getthere: leg focus autonoom vervoer meer op infrastructuur**	[65]
		30	**De zelfrijdende auto: dilemma's van de wegbeheerder**	[66]
Infrastructure Marking	**Zelfrijdende auto Nederland markering**	31	**Dit is de toekomst van zelfdenkende voertuigen**	[67]
		32	**5 obstakels die de zelfrijdende auto nog moet overwinnen**	[68]
Infrastructure Bike lane	**Zelfrijdende auto Nederland Fietspaden**	33	**Zelfrijdende auto's in Nederland: Fietsers zijn een probleem**	[69]
		34	**Zelfrijdende busjes blijken moeilijk samen te gaan met fietsers**	[70]
Infrastructure Traffic circle	**Zelfrijdende auto Nederland Rotondes**	35	**Onderzoek TU/e legt basis voor autonoom rijden op rotondes**	[71]
		36	**Autoweg van de toekomst: smalle rijstroken en weg met rotondes**	[72]

Infrastructure road narrowing	**Zelfrijdende auto Nederland Wegversmalling**	37	**Toekomst met zelfrijdende auto's vraagt andere kijk op wegbeheer**	[73]
		38	**Daimler gaat zelfherstellende HERE Maps gebruiken voor autonome Mercedes**	[74]
Infrastructure intersection	**Zelfrijdende auto Nederland Kruispunt OR Oversteekplaats**	39	**Slimme auto kan verkeerslicht overbodig maken**	[75]
		40	**'Zelfrijdende auto zou op Amsterdamse kruising uren stilstaan'**	[76]

7.1 Perspective Law and Regulation

Laws and Regulations Worldwide.

In terms of laws and regulations, the document analysis reveals that several countries are focusing on developing autonomous driving. In the U.S., China, Europe, Australia, Japan, Singapore and other countries, the government is committed to Autonomous Driving (Sources: 2, 3, 5, 8, 10). This is evident from laws and regulations, which are being implemented in these countries (Sources: 2, 3, 5, 9, 10). For example, there is a global trend, where laws and regulations are being prepared or amended for allowing autonomous cars on the road and/or autonomous features (Sources: 1, 7, 9, 10). In addition, legislation is being made for testing AVs and their features before they are allowed on the road (Source: 5). Pilots are also being allowed in several countries, testing at different levels of autonomous driving or autonomous features (Sources: 5, 9, 10). Finally, the development of autonomous driving is also evident in the development of laws and regulations regarding liability (Sources: 3, 5, 8). This shows that countries are preparing for the potential introduction and acceptance of autonomous driving. At the same time, we see that countries are also facing obstacles when it comes to laws and regulations for autonomous driving in the areas of road safety, privacy, cybersecurity and liability (Sources: 5, 7, 8). The degree of permitting varies by country/region, underlying a major dilemma. On the one hand, governments want to support innovation, given the many benefits that autonomous driving can bring. Benefits identified in the articles include economic and social benefits and safety (Sources: 9, 10). For the economy, opening up the country to autonomous cars and or pilots can generate a large number of investments, for example, in the auto industry, (digital and physical) infrastructure and services that come from autonomous cars (cabs, etc.) (Sources: 8, 9). In addition, AVs offer opportunities in the social sphere, think of improving mobility for people without driving licenses, the elderly, the young, the disabled, etc., as well as safety and environmental impact (Sources: 9). On the other hand, there are also motives for a government to be careful in making laws and regulations that allow AVs on the road. In this, ensuring safety, liability, privacy and support plays an important role (Sources: 1, 2, 3, 5, 7), which gives governments a conservative attitude when it comes to opening laws and regulations to the technology of AVs. In China, for example, fully autonomous cars are already allowed in some cities using advanced technology, such as to navigate roads, stop at red lights, and avoid pedestrians and cyclists. While in Europe it is still in the experimental phase (Source: 6).

Nevertheless, an increasing trend can be seen, with more and more countries gradually opening up to AVs (Sources: 8, 9). Permits are being issued for pilots, where autonomous driving is allowed to a greater or lesser extent (Sources 8, 9). In some countries, fully autonomous driving is opened up under certain conditions. Examples of conditions include speed, specifically designated areas or requiring a human backup driver, who can take over at any time (Sources: 6, 9, 10).
Other countries or regions choose to allow partial autonomous features, such as using adaptive cruise control, automatic parking, lane-keeping systems and intelligent speed adaptation (Sources:7).
Furthermore, systems are being established in several countries that track data on AVs from AV manufacturers, electrical component suppliers, network operators and service providers, whether mandatory or not. Data is also tracked on accidents and other issues, which help developers keep AVs as safe as possible.
Worldwide, countries are working together to address global issues. Countries, including USA, all European countries, China, Japan, Korea, Australia and South Africa, are participating in the work of GRVA (Working Party on Automated/Autonomous and Connected Vehicles), which mobilizes global expertise from key industries, such as the automotive, IT, telecoms and insurance sectors, together with civil society. Key issues identified and currently focused on are safety measures, connectivity, cybersecurity and software updates, testing methods and safe integration of AVs in road traffic and uniformity. Collaboration between the parties is essential to address complex challenges for the social, environmental and safety benefits of AVs (Sources: 2, 3).

Laws and Regulations Europe
Europe aims to pioneer fully autonomous cars. In the summer of 2022, the European commission declared its intention to implement technical rules for the introduction of driverless vehicles. These technical rules mean that vehicles must meet certain standards. Here it is focusing on regulations for automated vehicles that replace the driver on highways (automation level 3) and fully driverless vehicles such as urban shuttles or robotic cabs (automation level 4). The technical regulations cover testing procedures, cybersecurity requirements, data recording rules, and safety performance monitoring and incident reporting requirements by manufacturers of fully driverless vehicles. The technical regulations aim to increase public confidence in AVs. In addition, the rules should boost innovation and improve the competitive position of the European automotive industry (Source: 1).
Besides legislating to enable AVs on the road, autonomous features are also becoming mandatory for new vehicles. For example, the European Commission has introduced new legislation that requires all new vehicles to have certain autonomous features that support the driver while driving. Examples of safety measures taken for all road vehicles (i.e. cars, vans, trucks and buses) are intelligent speed assistance, reversing detection with camera or sensors, attention warning in case of driver drowsiness or distraction, event data recorders as well as an emergency stop signal. For cars and vans there are additional features such as lane keeping systems and automated breaking. For buses and trucks there are technologies for better recognizing possible blind spots, warnings to prevent collisions with pedestrians or cyclists and tire pressure monitoring systems (Source:1). Now

partial autonomous features are allowed, as mentioned above, but the driver is still fully responsible, both physically and legally, for the actual behavior of the vehicle (Source:7).

The EU has released a draft version of legislation, which automated driving systems (ADS) must comply with. This includes what ADS must be capable of. It distinguishes between normal traffic scenarios, critical traffic scenarios, failure events, and minimum risk maneuver. For example, ADS must show how it interacts with other road users, including motorcycles, bicycles, pedestrians, and obstacles (e.g. debris, lost cargo). It must be able to respond to accidents, traffic jams, road works, road safety officers and law enforcement agents, emergency vehicles, traffic signs, road markings, and environmental conditions. Critical scenarios mean that the collusion must be able to assess risks, unexpected obstacles on the road and be able to respond to them to minimize the risk of accidents and congestion. It also specifies that ADS should not weigh whose life it is risking when a choice has to be made. In addition, the safety of the road user inside the vehicle must not take precedence over a road user outside the vehicle. There is also a maximum speed reduction value, which stands at 4 m/s for a minimum risk maneuver. Also, ADS must be able to recognize Operational Design Domain (ODD) ODD conditions, such as rain, snow, fog, time of day, light intensity, road and lane markings, and geographical area. The manufacturer should specify these and set ADS to take action, as needed. Finally, there are also cybersecurity requirements that ADS with meet, as well as meeting software management requirements such as performing updates (Source: 4).
Furthermore, the EU is focused on developing reliable AV development policies. For example, the EU is a forerunner when it comes to regulations for protecting personal data, and legislation has been introduced specifically for the AV industry focused on cybersecurity and privacy. In addition to setting up a common European mobility data space, it has also introduced regulations aimed at securing AV-related datasets (Source: 3). Finally, the EU is also focusing on uniformity. This was decided at a meeting of EU ministers in Amsterdam, in 2016, where an agreement was made to work towards a coherent European framework for the deployment of inter-operable connected and automated driving (Source: 10).

Laws and Regulations Netherlands
The Dutch government has set the goal of being a leader in developing and implementing autonomous driving and autonomous features (Sources: 8, 10). The Netherlands believes in the promise of autonomous driving in terms of safety, efficiency, environmental impact, economic growth and job opportunities (Sources: 9). For this, it opens itself up by making laws and regulations that enable testing through law governing the experimental use of self-driving vehicles (Source: 8, 9, 10). This includes, for example, that various conditions and circumstances must be taken into account, such as time of day, location, weather conditions, type of road, trained drivers, interaction with other road users, possible physical accompaniment, additional insurance requirements, etc. (Source: 9) Furthermore, the Netherlands is also in the process of establishing requirements for allowing AVs to drive in the Netherlands. For example, the Netherlands is developing a driving license for autonomous cars (Source: 7) and is setting up standards for cybersecurity (Source: 7). In addition, the country is investing in physical and digital infrastructure, among other things, to provide support facilities (Sources: 7, 9). In the Netherlands, several challenges remain. The Netherlands is still in the experimental stages, where the technology is still developing, the current infrastructure is not yet ready for it, there is still a lack of legalization and manufacturers cannot yet provide sufficient guarantees in terms of software updates, among other things. This development, in terms

of laws and regulations, shows that there are high expectations on the further entry of autonomous transport into society. The extent to which and how autonomous driving could be allowed is still unclear but is in the process of development. The drafting of laws and regulations will still take time, which for now is still delaying the introduction of AVs in the Netherlands (Source: 7).

All this shows that there is a trend toward allowing more autonomous cars on the road in terms of laws and regulations, but also that there are still many obstacles, when it comes to laws and regulations, that hinder feasibility.

7.2 Perspective Manufacturers

Besides the government, manufacturers are a major influence on the success of AVs in urban areas. They invest in and develop the technology for AVs. The document analysis for this category focuses on their perspective regarding the feasibility of AVs in urban areas. Both websites of four major AV manufacturers and as well as articles about these AV manufacturers were searched. The purpose of this is to validate previous conclusions match reality.

Vision of Manufacturers

Manufacturers have a positive view of the potential of AVs in urban areas. For example, they see opportunities in safety (Sources:12, 16, 17, 18, 19, 20), effectiveness (Sources:11, 16, 17, 18, 19, 20), durability (Sources:16, 17), and comfort (Sources:12, 14, 15, 16,18). AVs already possess several automation features (automation level 2) required for feasibility such as: steering assistance (Sources:12, 14, 15, 16, 19, 20), detecting lane markings and lane edges (Sources:12,14, 15, 16, 19, 20), lane keeping (Sources:12, 14, 15, 20), lane changing (Sources:12, 15, 20), speed control (Sources:14, 15, 16, 20), automatic lighting (Sources: 12, 20), Emergency Stop and Break Assistance (Sources: 12, 15, 16, 19, 20), recognizing traffic lights and communications (Sources: 15, 16, 19, 20), recognizing collision and crossings (Sources: 12, 15, 16, 20), navigating out of complex environments (Sources: 14, 15, 20), auto-park (Sources: 12, 14, 15, 20), navigation (Sources: 14, 15, 16, 20), dealing with uncertainty of object behind other objects, (Sources: 16, 20) Also, features can detect blue lights from emergency vehicles (Source: 12), wetness sensors exist (Source: 12) and data is collected by LIDAR (LIght Detection And Ranging), radar and ultrasonic sensors and cameras, which collect information over-road geometry, route characteristics, landmarks or traffic signs and unusual traffic events (e.g. accidents or roadworks) (Sources: 12, 19, 20). There is also AVs software, which aim to avoid or prevent accidents (Source: 20). In addition, AVs are capable of autonomous driving under various preconceived conditions/conditions (automation level 3) (Sources: 12, 16). Examples of conditions, which can be a requirement for autonomous driving with AVs, are: max speed limit (60km/h) (Sources: 14, 16), designated roads/areas (Sources: 17, 19, 20) and weather conditions (Sources: 16, 20).

Furthermore, an AV is capable of fully autonomous driving in, for example, a parking lot (automation level 4) using corresponding infrastructure (Source: 12). Here, an AV is also able to stop for all types of obstacles, including for example pedestrians, cyclists, vehicle types and road details such as lane lines, construction zones and signage as well as moving objects (Sources: 12, 16, 19). AVs are able to distinguish between different road users and objects (Source: 19).

Waymo, a self-driving car manufacturer (part of Google/Alphabet) explains the process of their AV using 4 steps.
The first step is determining the location in a pre-defined map, which contains information about road profiles, curbs and sidewalks, lane markers, crosswalks, traffic lights, stop signs, and other road features. Using GPS and real-time sensor data, the location of the car in the map is determined.
Step 2 is to identify objects, such as pedestrians, cyclists, vehicles, road work, obstructions, around the AV using sensors and software scans. In addition, it continuously scans for traffic controls, from traffic light color and railroad crossing gates to temporary stop signs. Step 3 is predicting future/expected movements of objects based on current speed and trajectory. An AV takes into account different movement methods, for example a bicycle or a pedestrian, and it takes into account how changing road conditions, such as a blocked lane, may impact the behavior of others around it.
Step 4 is determining one's route by selecting an exact trajectory, speed, lane, and steering maneuvers needed to progress along this route safely.

Manufacturers focus on security (Sources: 12, 14, 15, 16, 19, 20) and reliability (Sources: 12, 14, 16, 19, 20). For example, manufacturers are focusing on security architecture, about which Mercedes says it is betting on sensor redundancy, among other things, to ensure security (Sources: 14, 19, 20). However, manufacturers also see major challenges. Challenges in the areas of legalization (Sources: 12, 13, 15), liability (Source: 13), ethical issues (Source: 13) and data protection (Source: 13).

As for legalization, they argue for uniformity (Source: 13).
Specifically, for urban areas, they also see other major challenges. The challenge lies in the more complex, not uniform, road layouts, processes and possible scenarios (Source: 11) and that there are many different road users interacting in a relatively confined space (Sources 11, 20). AVs should be able to recognize the environment (Sources: 11, 19, 20), cooperate with maps and locations (Sources: 11, 19, 20), react correctly in any situation (Sources: 11, 20), have a good human - vehicle interaction (Sources: 11, 19, 20). Examples of complex road situations are junctions, traffic circles or when interacting with more vulnerable road users (Sources: 11, 19). It also focuses on cyber security to protect IT systems (Sources: 16, 19, 20). Furthermore, General Motors says it focuses on testing under all conditions, such as lighting, weather conditions and traffic conditions (Sources: 16, 19, 20). GM tests for the ability to detect, predict and react (Sources: 16, 20).
The manufacturers' documents found give the impression, that it is only a matter of time before autonomous cars are possible on the road. It also emphasizes that safety is a top priority, with which they want to gain the public's trust.

Third-party Reactions to Manufacturers' Views
In addition to searching manufacturers' documents, we also looked at news from others about manufacturers in relation to the feasibility of autonomous driving. This shows that there is progress in development when it comes to introducing autonomous driving. Several pilots are already underway in several cities (Sources: 21, 22, 25), which are generally safely ahead of the curve. Driving autonomous cars in cities has a promising future, including in the areas of robot cab services, robot-driven delivery and truck transport (Source: 21). However, issues have surfaced with AVs, which have resulted in accidents, fatal or otherwise (Sources: 21, 24). In addition, other issues have surfaced involving AVs, such as causing obstructed traffic, caused delays to transit services, clogged

up bus lanes or interfered with firefighters (Source: 25). Furthermore, there are also sounds, which indicate that AVs are not yet always able to get themselves out of complex situations and that current systems are not robust enough to navigate cars autonomously in real-world traffic, such as recognizing fake traffic signs (Source: 22). Also, a good business model is still a challenge for the time being, as the costs are high for AVs (Source: 21) and because regulation is still in development and manufacturers are still highly liable, which is risky (Source: 21). Also, there are still technical complexities which are growing with unpredictable traffic patterns and weather factors such as fog, rain and snow on markings (Sources: 21, 23). Finally, there is a challenge in terms of social awareness and acceptance (Source: 21). In addition to the potentials and challenges, conditions have been identified that can contribute to safely allowing AVs on roads in urban areas. Examples are setting up a speed limit (30km/h) (Source: 22), more curbside interactions require cities to redesign street features like sidewalks (Source: 24).

7.3 Perspective Infrastructure

Infrastructure in general

From the document analysis, focusing on the feasibility of AVs in the Netherlands in relation to infrastructure, a more cautious picture emerges, than that shared by the manufacturers. The reason for this is that the development of the self-driving car is not in sync with the development of infrastructure for AVs.

On the one hand, the Netherlands is seen as one of the best prepared countries for the arrival of AVs. This, because it scores high on the following four factors: technology, user acceptance, legislation and infrastructure (Source: 28). This is also evident from the "spectacular pilots" being conducted in the Netherlands, such as autonomous park shuttles as a form of public transport in Capelle aan den IJssel, among other places (Sources: 27, 29). Park shuttles are used as a popular "last mile" solution. The shuttles transport people and travel along predefined routes. maintain a maximum speed of 15 to 21 km/h. In Capelle aan den IJssel, it has now been decided to extend the route to a larger area, with some of it being driven on public roads (Sources: 27, 29).

On the other hand, there are still enough challenges and obstacles, which are holding back the introduction. For example, the Netherlands has a greater challenge compared to other countries due to the large numbers of cyclists on the road (Source: 28). Another challenge in the Netherlands are the narrow roads compared to other countries. This comes from the fact that the Netherlands is a small country and relatively densely populated (Sources: 28). As a result, different road users drive close together.

In the documents found on AVs in relation to Dutch infrastructure, there are different views on the chances of success for introducing AVs on Dutch roads. This depends on the type of scenario.

For example, there are scenarios with many or fewer numbers of obstacles on roads. Consider the difference between highways with fewer obstacles for AVs, given the uniform infrastructure there and the absence of vulnerable road users, such as cyclists and pedestrians and, on the other hand, the challenging infrastructure within urban areas, combined with the presence of cyclists and pedestrians (Sources: 28, 29). The interaction between AV and human road users makes them vulnerable and possibly leads to different behaviors. For example, it is suggested that human road users, such as cyclists and pedestrians, are more cautious in crossing when an AV passes by (Sources:

27, 28). However, there are also studies that claim that as road users become more accustomed to the characteristics of AVs, they become more positive about them, but also that they are less likely to give AVs the right of way (Source: 27). Communication between AVs and other conventional road users can be improved by equipping the AV with capabilities to provide signals to make it clear to fellow road users what it is about to do. An example communicating messages such as "I am driving on" or "I am going to stop" (Source: 27).
In addition, scenarios can be distinguished with fully autonomous driving vehicles and vehicles equipped with autonomous features, which support the driver (Sources: 27, 30). Thus, experts are skeptical about fully AVs, while it is expected that far-reaching support, using autonomous features is possible. From the documents found, it appears that success may lie primarily in supporting the driver with features such as a warning when the vehicle leaves the lane (Lane Departure Warning) or with an emergency braking system (Autonomous Emergency Brake) (Source: 27).

Furthermore, a distinction is also made between scenarios where only fully AVs are allowed on roads and scenarios where AVs are allowed on roads along with current conventional vehicles. In cases where both are allowed, the challenge is greater than on roads where only AVs are allowed (Source: 27). In the case of the scenario where a combination of AVs and non-AVs are allowed on the road, one option is to create separate lanes for AVs and non-AVs (Source: 27).

Finally, there is consideration of different types of technologies, which an autonomous car should be equipped with. Types of technologies are: (1) AVs driving on digital maps, with information about the roads (Source: 26), (2) AVs guided by sensors (Source: 26, 27) or (3) AVs, communicating with other AVs or the infrastructure (Source: 27). For each type of scenario, different requirements are needed when it comes to infrastructure and there are different expectations regarding feasibility. For example, for AVs, using digital maps, it is important that maps are updated real time/recently. Important types of information are: administrative information about addresses, vehicles allowed per road (pedestrians, cyclist, cars, motorcycles, scooters, buses, cabs, emergency services, etc.), direction of travel, road category, road characteristic, such as speed limit, number of lanes, road markings (lines and road signs), location of dynamic speed signs (matrix signs), turn prohibitions/ mandatory direction of travel, dimension restrictions (height, length, width, weight, axle pressure, hazardous materials, etc.). But also, information about the exact location and shape of traffic facilities (traffic signs, traffic lights, crash barriers, matrix signs, road markings - especially priority signs, etc.) should be up to date. The same applies to real-time (traffic) information about traffic jams and accidents, closures, road works and reconstructions and the current dynamic speed limit, temporary road diversions, the current location of ferries, etc. (Source: 26).
For sensors, it is important that the road be recognizable and uniform. This means there is great pressure for maintenance. Motorists, when markings are worn out, are able to estimate how they pass, but the question is whether the same is true for AV sensors. If not, then the challenge of maintaining markings continuously at 100% is great, if not impossible. Also, there are still roads without markings, which requires good coordination, between creators of systems and road authorities, both nationally and internationally (European) (Source: 30).

The use of AV technology, which allows AVs to communicate with each other or with infrastructure, makes possible any adjustments to traffic intersections. For AVs in the Netherlands, for example, traffic circles are no longer a logical choice for handling traffic. Traffic circles are now seen as safe

because road users can connect motorists with each other. But AVs communicate with each other, so these intersection types are no longer necessary, and a conventional intersection is sufficient (Source: 30).
The difference in safety margin of conventional cars and AVs also plays a significant role in choosing road network modifications. In crowded situations, such as when merging onto the highway, conventional vehicles are able to squeeze themselves in between. The car driver may only need 5m of space, where AVs need 10m. After all, an AV cannot interact anticipatively with "normal" traffic. This raises the question of whether, on the contrary, longer merge lanes are needed for AVs.
Another example are intersections with lanes consisting of a single lane, "spaghetti roads." These roads are made for the safety of driving conventional cars. But communicating self-driving cars can actually drive very well on multi-lane roads. Therefore, AVs that have different safety margins than conventional vehicles may influence the choice of road modifications (Source: 30). Vulnerabilities cited with AVs are faults in the system, such as algorithms not working properly or broken sensors (Source: 27). In addition, an AV can be prepared for many situations, but the challenge lies mainly in unforeseen situations (Source: 27).
The relationship of the driver to the system when driving in an AV is also considered a challenging factor. Can the driver rely on the system and are the responsibilities for specific tasks of the driver and the system clear (Source: 27)?

Advantages are also mentioned, such as that AVs can lead to shared transportation, reducing the need for parking spaces (Source: 27), given the possibility that AVs pass on to other individuals, who want to use them. This space could be used for safety measures such as wider or separated bike lanes, among others.

One paper argues for a shift in focus to adapting traffic infrastructure rather than the technology that makes the car itself autonomous. In this way, semi-autonomous vehicles can gradually evolve into fully AVs (Source: 29). "Start with automated transportation in controlled environments (automation level 4), and then incrementally make those environments slightly less controlled. This will allow the technology to mature slowly, without compromising passenger safety" (Source: 29).

Specific Infrastructure Elements

As indicated earlier, within this "infrastructure" category, we searched for documents indicating the relationship between AVs and five specific infrastructure elements. The five specific infrastructure elements are: markings, bike lanes, traffic circles, road narrowings and intersections/crossings.

Marking

Roadway marking is important to an AV. It helps determine the position of the vehicle. An AV depends on sensors combined with artificial intelligence to see and recognize the marking. Seeing the marking can be compromised by bad weather, such as snow, rain or a shadow. Bumps in the road surface, such as potholes, can also be overlooked by the vehicle.
For this, the artificial intelligence must be well-trained from data.
Google reports show that during test drives, bad weather is often a cause of dangerous situations, where the test driver had to take over the vehicle. There was also an accident in March 2018, with a fatality, due to the AV misinterpreting the road markings. As for potholes, they may also be recognized but the AV may not make the right decision. For example, in the case of filled potholes,

which look different from a normal road surface (Source: 31, 32).
In case of automation level 3, a driver can be called to take over the steering. However, it is then questionable whether a driver is able to react in time. There is also a high probability that a driver will not pay attention at all. Another identified issue to consider is that unpredictable drivers, who do not follow the rules, can also be a danger to AVs. A support to AV technology, which drives on road markings is driving on digital maps. Here, the AV recognizes road markings, which are incorporated into a digital map. Here it is important that maps stay well up to date, so that AVs are aware of changed traffic situations or road works (Source: 31).

Bicycle Paths

Cyclists are a large group of road users in the Netherlands and have a strong culture. This proves to be a big challenge for AVs, as cyclists in the Netherlands often do not follow the rules, are a vulnerable group and in terms of behavior difficult to predict. Now cyclists and mobilists recognize each other's behavior based on eye contact, but this is a big challenge for AVs. What AVs can already do is recognize cyclists with an outstretched hand, but this is rarely done in practice. In addition, cyclists regularly cycle through red lights. Also, cycling culture is different in each country and sometimes city, which adds to the challenge. AVs should be able to recognize cyclists and predict behavior. One possible option is to equip bicycles with a communication device so that they can communicate with AVs. However, then every cyclist must have such a device. Another option is to teach AVs to predict cyclist behavior based on the front wheel, but that is currently not possible and may be too challenging. Standard stopping is not an option in crowded cycling areas because then there will be no progress. A possible option then is as a driver to actively communicate himself. By indicating what the AV is going to do, for example by light signals or making noise. Separate bike lanes seem the best alternative, in combination with traffic lights, which regulate traffic, but the question is whether there is room for this everywhere and is probably a costly investment (Source: 33). In Friesland, self-driving vans were temporarily taken off the road, following complaints. Cyclists had to avoid the vans, which took up a lot of space. The vans were not good at swerve. Cyclists expected the vans to swerve in front of them, but they did not. The vans did stop in time if a cyclist got too close. Some people acted cautiously and waited until the vans had passed them. The pilot continued with hosts and ladies giving instructions to the rest of the road users on how to deal with the vans (Source: 34).

Traffic Circles

Traffic circles are common in the current road network within built-up areas. Traffic circles are designed to force through traffic to reduce speed. It is one of many infrastructure elements that an AV has to deal with when it is introduced on the roads. The usefulness of the traffic circle disappears the moment roads are fully occupied by AVs, since AVs are capable of automatically adjusting their own speed and human behavior is no longer a factor in this (Source: 36). Still, AVs have to deal with traffic circles as long as they are still part of the road network. The papers show that AVs are perfectly capable of driving over traffic circles when it uses a combination of sensor data and map data (Source: 35).

Road Narrowing

For AVs, roadway narrows are challenging obstacles. This is because AVs have set safety margins that the AVs must adhere to. For example, it maintains a margin of 10m. At a road narrowing, it can go wrong because of this. In addition, it has to deal with other vehicles around it (Source: 37). A possible solution to this is digital maps, which provide information to AVs. These maps should be constantly updated, for example with own data, but also with sensor data from AVs (Source: 38).

Intersections

AVs combined with smart intersections can lead to improved efficiency on the road. It can lead to a flow that can handle 2 to 3 times more traffic. It becomes more complex, however, when cyclists and/or pedestrians are involved. Since they require a different form of communication., That can lead to "over-stimulated" cars, standing still for long periods of time in front of a crosswalk or intersection. Especially in inner cities, where it is very busy (Source: 39, 40).

7.4 Conclusions Document Analysis

The document analysis focused on 3 categories: laws and regulations, manufacturers and infrastructure. The following conclusions can be drawn from the documents consulted.

Laws and Regulations

Worldwide

In terms of laws and regulations, there is a global trend of governments preparing and implementing laws and regulations with the goal of allowing autonomous cars on the road and/or autonomous features. Among other things, the laws and regulations focus on specifying quality and authorization requirements and procedures for testing AVs before they are allowed on public roads. It also focuses on permitting and specifying conditions for various pilots of AVs on public roads. Governments see benefits in terms of safety, effectiveness, as well as economic and social benefits. Challenges they see in the areas of privacy, liability, cybersecurity and ethical issues. The goal of regulation is to maintain security and support. The current state is that in some countries AVs are already allowed (China) and in others, including the U.S. and countries in Europe, pilots are being done. The pilots are still conducted mainly under certain conditions, such as within specifically designated areas with a maximum speed limit, a driver who can intervene at any time or allowing only certain autonomous features. Some countries are requiring the industry to use certain databases on accidents, cybersecurity and data, with the goal of learning from each other and ensuring security.

Europe

Europe wants to pioneer AVs and has already legislated, in part, to allow AVs on the road. Europe makes technical regulations, which set standards that AVs must meet. It is also drawing up legislation requiring AVs to use autonomous features (intelligent speed assistance, reversing detection with camera or sensors, attention warning in case of driver drowsiness or distraction, event data recorders as well as an emergency stop signal, lane keeping systems and automated breaking, blind spots recognition, pedestrians or cyclists warning systems and tire pressure monitoring systems). Currently, driver is still fully responsible, both physically and legally, for the actual behavior of the vehicle. However, this may change in the future. Furthermore, Europe is focusing on making laws and regulations specifically for the AV industry, focusing on cybersecurity and privacy. Europe has also introduced regulations aimed at securing AV-related datasets and the EU is also focusing on the uniformity of regulations for technology and infrastructure.

Netherlands

The Netherlands wants to lead the way and be a testing ground for AVs. It has drafted laws and regulations opening itself up to conduct pilots in the Netherlands. The pilots must meet certain conditions regarding time of day, location, weather conditions, type of road, trained drivers, interaction with other road users, possible physical accompaniment and additional insurance requirements. The Netherlands is also developing a driver's license for AVs, setting standards for cybersecurity, requiring guarantees for the possibility of software updates and developing laws and regulations on liability, among other things.

Manufacturers

The four manufacturers considered have a positive view of the feasibility of AVs on public roads. They see the benefits in terms of safety, effectiveness, comfort and durability. The technology is under development, with several features already in use (lane and marking detection, lane keeping, lane changing, steering assistance, speed control, automatic lowering, emergency stop and break assistance, traffic light recognition and communication, collision and crossing recognition, object identification, auto park, navigation, emergency vehicle detection and wetness detection). In addition, several successful pilots have already been conducted and emphasize that safety is the top priority. Nevertheless, there have been several fatal accidents involving an AV. The manufacturers themselves see challenges mainly in the areas of laws and regulations, liability, ethical choices and data protection. Currently, however, manufacturers are still struggling to get AVs to deal with complex situations. Examples include crowded areas with many pedestrians and cyclists, variation in weather phenomena such as snow on markings and recognizing fake traffic signs. Also, during pilots, AVs caused obstructed traffic, caused delays to transit services, clogged up bus lanes or interfered with firefighters. They suggest that AVs can be introduced under certain conditions, including maximum speed limits. They also call for uniformity in regulations and redesign of infrastructure such as sidewalks and more uniform markings.

Infrastructure

In the area of infrastructure, there are different signals, in terms of feasibility in the Netherlands. On the one hand, the Netherlands scores high when it comes to the best prepared countries, based on four factors: technology, user acceptance, legislation and infrastructure. And also, several successful pilots are already being held in the Netherlands, including with shuttle vans, with a maximum speed (15-21 km/h) along predefined routes, as a last-mile solution. On the other hand, challenges remain. For example, the Netherlands is a densely populated country, with a large vulnerable group of cyclists and has many narrow roads. As a result, all the different types of road users are close together. Furthermore, highways are uniform and well maintained, but the closer you get to and deeper into built-up areas, the less uniform the roads are. Here you also have to take into account many pedestrians, cyclists and other vulnerable road users. This leads to a lot of interaction, which makes it challenging. AVs have a difference in safety margin compared to conventional road users, so AVs will have difficulty in congested areas. However, there are several approaches regarding technologies to allow AVs to drive on roads. The first approach is to use digital maps, i.e., preconceived areas, that are fully mapped; this requires a real-life up-to-date map, as well as detailed information on road specifications, road works and traffic situations.

The second approach places more emphasis on the use of AVs sensors combined with artificial intelligence. Here, developing AI is important and roads must be recognizable, well-maintained and uniform. The third approach is communication with infrastructure. This requires modifications to infrastructure, such as removing traffic circles, introducing smart traffic lights and requires a reliable Wi-Fi network (5G). Furthermore, roads, where only AVs are allowed, can be merged. In other words, roads separated by infrastructure can be eliminated and longer entry lanes are desired due to the greater safety margin used by AVs. Finally, a major benefit is the reduced number of parking spaces required, which provides space on the roads. This can be used for other purposes.

Marking

Marking is of great importance for road recognition. Using sensors and artificial intelligence, AVs are able to recognize markings and determine their position on the road. Crucially, markings must be uniform, well maintained and recognizable at all times (fog, snow and darkness). Proper maintenance can be expensive. Roadwork should also be clearly recognized to avoid accidents.

Bike lanes

A combination of AVs and cyclists on the road is still very challenging, but possibly not unthinkable in the future. Especially on roads where there are not too many cyclists. There are already pilots where AVs ride together with cyclists on the road. However, cycling behavior is difficult to predict for AVs (difficult to recognize and cyclists do not follow the rules). Technologies already exist for recognizing cyclist behavior (recognition of outstretched hand) and there are also possibilities to use technology to predict behavior (front tire). Possible solutions include explicit communication by AVs (light signals and sounds) and separating bike lanes where possible.

Traffic Circles

For AVs, traffic circles are not necessary to safely handle traffic, as AVs are able to automatically adjust their own speed and human behavior is no longer a factor. As long as AVs have to deal with traffic circles, they are perfectly capable of driving over traffic circles if it uses a combination of sensor data and map data. In addition, AVs can communicate with each other, eliminating the function of even traffic handling.

Road Narrowing

Roadway narrows are challenging obstacles for AVs, but not impossible. AVs have a greater safety margin than humans and have more difficulty enforcing a spot on the road. These obstacles can be overcome through up-to-date digital maps combined with proprietary sensor technology and communication with other AVs or the infrastructure.

Intersections

Intersections themselves are not a challenge for AVs but become more challenging as pedestrians and cyclists are added. Many cyclists and pedestrians can overstimulate AVs, which should be avoided. If they are part of a communication system (traffic signals) it is not a problem and can improve efficiency considerably. If that is not possible, then AVs are not appropriate on these types of roads at this time.

8 Research Results

This section synthesizes the findings from the theoretical framework, expert interviews and document analysis. From these, an answer to the research question is formed. The feasibility of AVs within built-up areas depends on several aspects, including technology, legislation, infrastructure and user acceptance. In all areas there is development but there are also major challenges. Whereas autonomous driving is already possible on highways under certain conditions, the question arises as to whether it is also possible within built-up areas.

Technology

There are several technologies developed or in development, found in the literature, that an AV can apply to get from A to B safely. First, one can think of sensors around and inside the vehicle (examples are "IP (Internet Protocol) Camera", "Radar/LiDAR" (Light Detection And Ranging of Laser Imaging Detection And Ranging), and "Advanced Driver Assistance Systems (ADAS)")[8]. These use machine learning to recognize objects, including roads, road users, obstacles, etc.[17]. A key part of this is predicting behavior, which is challenging at the moment, especially with cyclists and pedestrians. This technology is expensive, because of the many sensors and easily affected by bad weather, poor light and "non-line-of-sight obstacles[8]. The sensors also need to be properly maintained, as broken sensors can cause problems. A major challenge here is developing the machine learning model in recognizing all road users and (unknown) obstacles, combined with predicting behavior. Privacy must also be taken into account. Sensor technology is already at a reasonable level, but requires development in improving quality and cost reduction[8][26].
A second technology is connectivity to the environment, including other AVs, infrastructure and network. This technology depends on good connectivity and developed infrastructure that can communicate with AVs. A more extensive form of this is the Vulnerable Road User Collision Warning (VRUCW) system. This surveys areas, where an AV intends to drive, supporting the AV[8]. This will require investment in a nationwide network, proper connection of AVs to the network (5G), investment in network security, and software and hardware that can be scaled up[31]. Infrastructure elements will also need to be equipped with digital components so that they can be digitally connect to the network and communicate with AVs (traffic lights, bridges, crosswalks, parking lots)[27].
A third technology added from the document analysis is the digital map, in which the AV drives over a digital map and uses sensors to determine its position relative to the digital map. This allows the AV to be alerted to poorly maintained roads, for example, and to be directed to the desired location. This is an intensive method and requires a well-documented digital map that is up-to-date combined with a widely deployed network. The digital map must remain up-to-date for any modifications and be verifiable with the observed reality from the AV.
Finally, the machine learning models, already play a role in recognizing objects[17]. But it is very advanced and needs to be well tested. According to the document analysis, machine learning indeed plays a big role, but it has difficulty in unpredictable situations. This is the challenge. For this, proper test will have to be developed[24]. For example, how does an AV deal with a hot air balloon landing on the road. Another example is predicting behavior of cyclists.
The technology is capable of driving AVs in many situations, including in built-up areas. It is just important to keep reliability at the forefront and focus primarily on what is technologically feasible for AVs. This requires a stable network, quality and affordable sensors, an up-to-date map and

good testing (especially for exceptional situations), for machine learning, among other things.
So as far as the technological side is concerned, it is not ready for autonomous driving in the inner city at the moment, due to the many factors and lots of unpredictable situations that can occur. For this, sensors need to be improved and costs need to be reduced. Investments will need to be made in reliable connectivity across all roads. Infrastructure elements will have to be replaced, wherever possible, by smart versions that can communicate with AVs. Machine learning tools will have to be further developed, especially for exceptional situations, including predicting driving behavior for cyclists. And finally, tests will have to be developed that test AVs on these kinds of situations.

Laws and regulations

In terms of laws and regulations, several issues have been identified in the literature, including the current lack of policy and regulations, liability, privacy and cyber security[17]. In the document analysis, these factors are also identified as challenges, but, the document analysis also shows that there is currently a worldwide trend to legally allow AVs. Furthermore, pilots are allowed with AVs under certain conditions. This research identified three main conditions under which pilots are allowed on the roads, namely maximum speed, backup driver and pre-defined areas. In addition, countries establish safety requirements that AVs must meet in order to be allowed on the road. However, challenges still apply when it comes to road safety (ethical issues, what choice does an AV make in the face of a dilemma), privacy (observation (sensors) of people around the AV, machine learning algorithms), cybersecurity (protecting AVs from hacking, misplaced road signs, etc.) and liability (who are responsible for accidents and for what part?). According to the literature and document analysis, databases are being set up to share knowledge in the areas of cybersecurity and privacy.
The document analysis also identified 2 opportunities on the way to AVs in urban areas. The first way is that legislation and regulations are also being drafted and partially implemented in Europe, requiring future vehicles to have certain autonomous features, including various warning systems and automatic braking in case of emergency (intelligent speed assistance, reversing detection with camera or sensors, attention warning in case of driver drowsiness or distraction, event data recorders as well as an emergency stop signal, lane keeping systems, automated breaking, recognizing possible blind spots, warnings to prevent collisions with pedestrians or cyclists and tire pressure monitoring systems).
As a second option, AVs can be allowed under certain conditions, such as setting a speed limit or having the entire area where AVs are allowed recorded on a digital map. This makes it possible to allow AVs without potentially causing unexpected situations. In addition, these types of areas can be used to learn from and perhaps increase control.
In terms of law and regulations, it is currently not feasible to allow AVs on a large scale within built-up areas. This would require more detailed legislation for liability, privacy, cybersecurity and minimum requirements or conditions that an AV must meet. However, the government is working on this, which in time is expected not to be an obstacle to the feasibility of urban areas AVs.

Infrastructure

In the area of infrastructure, certain requirements, challenges and opportunities have been identified. The literature, expert interviews and document analysis are all speaking of that a distinction can be made between a transition period, when AVs and human-driven vehicles are both part of traffic, and the period after that, when only AVs drive[27]. A distinction can also be made, in the

literature, expert interviews and document analysis, between roads with only AVs and roads where pedestrians, cyclists and other road users participate, and roads without them, which affects the road function. In the case of transition, human drivers will have to be taken into account, this means that traffic signs, traffic lights, street signs and other physical infrastructure should remain in place as long as human drivers are still using the road. In addition, it is important that human drivers and AVs, interpret all infrastructure in the same way.
Also, the literature, the expert interviews and the document analysis are talking about an interesting option, which is that AVs can communicate with infrastructure in different ways, such as traffic lights, bridges, crossing and parking lots. Current traffic lights can be replaced by traffic lights that can communicate through a network, which can improve traffic flow. Bridges can communicate when and for how long they are open. Intersections can communicate in advance whether a crossing is possible, reducing the need for braking, to the benefit of traffic flow. Parking lots can indicate how much space is available and where. Here, AVs can benefit less in terms of efficiency at the moment when human drivers also need to be taken into account[17][29]. Separate lanes may be partly a solution for this. However, this requires investment and the necessary space.
The moment human drivers are no longer needed, certain infrastructure can be removed, such as traffic lights, traffic circles, shoulders and guardrails[31].
In the process, roads can be narrowed, given AVs require less margin. However, this will lead to more maintenance, which can possibly be solved by in-programmed wheel-wander. In case of in-programmed wheel-wander, a wider road surface is needed[31][32].
There is also a distinction to be made between roads with only vehicles and roads where vulnerable road users also participate, such as pedestrians and cyclists. In the expert interviews, this revealed that the Netherlands distinguishes between roads with a traffic function, roads with a residential function and a combination of both. Roads with a residential function have many more obstacles and vulnerable road users, which increases the challenge. Examples of identified challenges and obstacles on these types of roads, according to the experts and document analysis, include speed reduction measures (speed humps, road blocks, chicanes), more intersections and crossings, no or a wide variety of markings, unclear roadside parking areas (along or perpendicular to the road, partly on the sidewalk, blue zones, etc.), multiple directions of travel on a roadway section, bicycle lanes on the roadway, greater variation in traffic signs, and overlap with public transportation and rail. For AVs, these obstacles should preferably be as uniform as possible and easily identifiable. The more an AV enters residential areas, the less uniformity there is. Certain minimum infrastructure features, such as markings, may be a requirement for AVs to be allowed to operate there. Also, maintenance of markings is extra important for AVs.
As in the expert interviews and found in the document analysis: in the Netherlands, a major challenge is the number of cyclists on the road. It is difficult for AVs to recognize what the cyclist's behavior is going to be. Separating roads and bike lanes as much as possible can help in allowing AVs to ride safely. Pilots have not shown, however, that AVs need to be unsafe for cyclists. Possible opportunities for this include better training of AVs in recognizing cyclists and their behavior based on the front tire, explicit communication from the AV or mandating a low speed for AVs, to avoid serious injury. However, it becomes more challenging for AVs when too many cyclists are present. Then the question arises of whether it is desirable to have AVs riding.
Another possibility is to set up mobility hubs, around places from which AVs are able to drive autonomously. For example, one or more in each neighborhood, accessible via access roads. Other places can then be reached by other means. This does mean limiting accessibility to certain areas.

Finally, it is also expected, according to the document analysis, that in the future, AVs may be able to drive in places where the amount of pedestrians and cyclists is limited, under certain conditions, such as at a maximum speed.

User acceptance

New technologies frequently face some form of resistance to development. Moreover, a new technology such as AV depends on public opinion. For this reason, it is up to the AV manufacturers, legislators and other stakeholders to gain public trust. Every accident will lower the confidence in AVs, while for every accident with an AV, there may be more accidents with vehicles driven by a human. The important thing here is to assess the risks of each step as best as possible and not take too much risk, resulting in losing the customer. Regulations can also play an important role in this, such as when it comes to liability for manufacturers and cybersecurity and privacy protections. Other possible options to improve user acceptance include providing education, marketing and advertising, building trust, putting safety first and outlining benefits.

Sub-conclusion

The current state of affairs is that various pilots are being conducted with AVs within built-up areas, but many challenges remain. There are multiple technological method, being persued to enable AVs within built-up areas. The development of AVs is still in progress and shows promising results for the time being. However, success depends on technological development and infrastructure investment. It seems likely that AVs will be able to drive in urbanized areas. However, this is more likely on road sections where there is no overlap with pedestrians and cyclists. This area can be increased by investment in separated lanes. Traffic lights can be used to create communication between AVs and pedestrians/bicyclists where needed. For areas where type of traffic participants will remain mixed, driving with AVs may be possible under certain conditions, such as limited speed, roadway uniformity or through the use of VRUCW -like systems. For example, in Capelle aan den IJssel, there are successful pilots with shuttles as a form of public transport, which have a maximum speed and operate in a restricted area. However, the challenge of allowing AVs in busy residential areas. This challenge seems too great for now. One solution may be a mobility hub nearby, with reduced accessibility via an AV as a consequence.

9 Conclusion & Recommendations

This study was designed to gain insight into the possibilities of introducing autonomous driving in built-up areas in the Netherlands. Various aspects, important for feasibility, have been inventoried. In particular the design of the roads and their surroundings were examined. A research question was formulated in order to gain insight into the possibilities and challenges of autonomous driving within built-up areas and thus its feasibility:

What influence do technology, laws and regulations, infrastructure and user acceptance have on the feasibility of autonomous driving in (Dutch) urban areas?

To answer this, this research zoomed in on the state of autonomous driving in general. The different levels of autonomous driving were discussed, as well as the availability of the technology and its opportunities and challenges. Feasibility was examined, based on 4 factors, namely technology, law and regulation, infrastructure and user acceptance. The differences between the use and infrastructure of roads outside built-up areas and those of roads inside built-up areas were further elaborated. This made it clear that autonomous driving within built-up areas, with a great diversity of infrastructure and road users, requires a very intensive and complex interaction between AVs and their environment. By interviewing experts and by studying documents on the subject, a picture of the feasibility of autonomous driving withing built-up areas was obtained, as well as the challenges. The following conclusions can be drawn:

- Autonomous driving is still under development. Technology development, where interaction with the environment is crucial, is estimated at TRL 6, or prototypes are demonstrated in their test environment. One is about to further demonstrate the innovation in an operational environment (TRL 7). These are particularly the less complex highways with separated lanes for one-way traffic and unambiguous road markings and road signs.

- Without the digital sensing, navigation, information and communication systems, AVs are not conceivable and therefore these systems require accurate, country-wide, reliable and hack-resistant internet connectivity for all types of roads. This is consistent with the literature[31]. This is optional since the Netherlands has already a strong network (for the connectivity), only rural places with roads should be maybe added to the network.

- In addition to the technological challenges, there are other challenges to getting autonomous driving accepted and implemented. To mention are legal challenges (think of liability (producer, owner, driver)), system integration (coordinating different types of observations and information), prediction and trust (being able to predict the behavior of road users), interaction between road users, (the communication between different road users about, for example, emerging traffic situations), learning ability (the ability to learn from experiences), scaling up (the further development from test phase to large-scale deployment, with everything that goes with it), verification and validation (the development of systems to continuously assess the performance of autonomous driving). Certainly not unimportant is to gain the trust of both the driver and all other road users. This is in line with the found literature[17] and is currently in progress according to the document analysis.

- Compared to the off-street traffic environment, the on-street traffic environment is much more complex. Outside built-up areas, national motorways and provincial roads are distinguished, which are characterized by their traffic function with a more limited variety of traffic participants, speed limits and road infrastructure, such as road lanes, road surface, markings, junctions, etc. Within built-up areas, roads have a residential function whether or not combined with a traffic function. Therefore, this variation is much greater. This demands a lot from the detection and recognition capabilities of AVs and thus the communication and interaction of AVs with their environment. This affects the programming of AVs.

- Information and communication systems will require the necessary adjustments to the infrastructure. We speak of road infrastructure factors. These include elements such as: geometric design, pavement structure, geotechnics, markings and signs, roadway safety devices, speed limits, hard shoulders, parking spaces, structural design of bridges, tunnels and underpasses, safe harbor areas, service and charging stations, traffic circles, changes across aterials collectors and local roads for AV operations, enhanced maintenance, introduction of new infrastructure elements and removal of existing infrastructure elements, redistribution of elements and redesign of elements.
  There should be information and communication systems for coordination with AVs on traffic rules and on-site directions in the form of markings and signs. This refers to readable and standardized (digital) traffic signs and other aids to enable safe traffic. At the same time, software development will have to ensure that all those markings and signs are recognized. It can be expected that in the final phase of transition when human-based driving is phased out, new forms of markings and signs will make current traffic signal systems and signs obsolete.

- The more efforts are made to standardize traffic rules, signs and other markings within municipalities in particular, the easier the programming of AVs will be. This is in line with the found literature.

- Autonomous driving will first have to prove itself on less complex roads, such as highways, before it is allowed within built-up areas. This has everything to do with the more complex conditions within built-up areas. It is not ruled out that additional innovations will be needed to allow AVs within built-up areas (such as machine learning techniques to predict behavior of cyclists,), according to the document analysis.

- In the transition to autonomous driving, the phase-out of current human-based driving is taking place simultaneously. During this period, both forms of driving coexist. This means that the construction and operation of new infrastructure must take both forms of driving into account, which is in line with the literature.

- It must be taken into account that autonomous driving is not possible in parts within built-up areas. For example, in busy downtown areas with a wide variety of traffic participants and complicated traffic intersections, or in residential areas with children playing and pets running loose. In such environments, one could choose for the speed limit to be between 15 and 30 km/h. Which is suggested by the expert interviews.

- A transition period of 30 years should be taken into account. During that time, provisions should be made that allow for a gradual transition from current human-based driving to autonomous driving, according to the experts.

All in all, achieving autonomous driving in Dutch urban areas will be a major challenge. The technological development is still in its early stages and uncertain, the traffic picture is very varied and the diversity of infrastructure and associated markings and signs is great, and moreover, little is yet known about the acceptance of autonomous driving by society.

Recommendations are:

- The technology is not yet fully ready for it, to run AVs in places, where many cyclists are present. Research into recognizing and predicting the behavior of cyclists could give a huge boost to feasibility. For example, using machine learning in combination with the front tire. This is a recommendation based on the document analysis. This is feasible, considering it does not take a huge investment and time to figure this out.

- For the standardization of infrastructure facilities, it is recommended to establish criteria. These include the standardisation of roads with separate uses for different types of road users, of markings and signs, of the implementation of functions such as parking, crossings and mobility hubs in residential areas, but also the application of unambiguous, uniform traffic rules. The recommendation for uniformity appears frequently in the literature[31][27]. In particular, the recommendation to separate AVs from other vehicles on highways. Within built-up areas, uniform solutions are desired for sharing road use with slower road users, such as bicyclists, mopeds, mobility scooters, etc. This study goes beyond the literature by recommending separating bike lanes from roads whenever possible. This will create a safer situation. However, this will require substantial investment and take years, but is an effective measure to allow AVs in many more places within built-up areas. It will be costly and time consuming, so difficult to implement. Future research should be done to identify the costs and benefits of a more uniform infrastructure in urban areas.

- It will be necessary to map in which areas within built-up areas autonomous driving is feasible. Taking into account the previously proposed criteria for standardization of roads, traffic situations can be designed for this, which enable safe participation of AVs in traffic. Based on the designed traffic situations, existing traffic situations can be evaluated, in terms of complies, does not comply or can be modified. Clear requirements and conditions (such as restricted areas and maximum speed limit between 15-30 km/h) must be set, so that the assessment makes it clear whether autonomous driving is allowed or not, whether or not after adapting the traffic situation.

- To get ahead of possible resistance, it is important to involve the public in the development of autonomous driving. They will need to have confidence in self-driving vehicles and therefor be able to participate in the development of scenarios for save and responsible participation of AVs in traffic. Further development is needed in several domains, such as on safety, legal domain, political domain, etc. A program and/or campaign in which people are informed can contribute to a positive attitude of the population towards the AV. This research recommends more research on psychological obstacles for the population and how to remove this resistance if it is not grounded.

- Research is needed on the behavior of drivers of AVs in an environment where autonomous driving is practiced. In particular, it will be necessary to understand how drivers react in situations where the car has the initiative.

- There are still many questions to be answered about how the transition from current driving to autonomous driving will take place responsibly and safely. For example, will AVs be allowed and introduced by road type or by area or region. Will areas transition at the same time or will it happen successively. Is a transition period desired with partially autonomous and non-autonomous cars and if so, for how long. All of this is a complex issue to resolve as there are many factors to consider.

This research identified several factors from the literature that affect the feasibility of AVs in urban areas. In addition several other factors relevant to the introduction of AVs in built-up areas were identified in terms of challenges, opportunities and conditions/requirements. The feasibility of all these factors were tested through expert interviews and document analysis. From this, the above recommendations were derived, which need further modification or investigation to increase the feasibility of AVs within built-up areas. In doing so, a set of requirements were established that are necessary for AVs to run. Ultimately, it is a political choice to allow AVs, where the choice is to meet the requirements needed, through investment.

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