The effect of autonomous vehicle reliability on people's intention to use them

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Abstract

Autonomous vehicles or AVs are the latest and most technological innovation of the automotive industry. AVs could bring many potential benefits by drastically reducing material requirements, air emissions, costs, travel times and accidents. However, it has been determined that people are very reluctant in their intention to use AVs. And one variable that seems missing from the theoretical framework regarding the intention to use AVs is that of reliability.

The goal of this research is to dive deeper into the realm of AV reliability and explore the effect of technology and system reliability on the intention to use AVs. The following research question has been formulated: what is the effect of technology reliability and system reliability on the intention to use autonomous vehicles? Technology reliability refers to the probability that the driving technology works without failures for a certain period of time. System reliability refers to the probability that the system around AVs works satisfactory to limit uncertainty about trip time. Based on the research question, two hypothesises were developed: (H1) technology reliability has a positive effect on the intention to use AVs and (H2) system reliability has a positive effect on the intention to use AVs.

To answer the two hypothesises, both an experiment and focus group were conducted. The experiment was done via an online questionnaire among Dutch respondents. Respondents were randomly distributed over four scenarios regarding the combination of; high or low technology reliability and high or low system reliability. Each respondent was shown one newspaper article containing one of the four scenarios. The focus group consisted of 8 Dutch respondents with different educational backgrounds. The results showed that technology reliability has a positive effect on the intention to use AVs. This was due to the high importance of safety related issues with technology reliability. The system reliability has no significant effect on the intention to use AVs. This was due to the familiarity of variating travel times in our current daily travel with cars and public transports.

Based on the results, the minimum requirement is to have a self-driving technology which is at least or more reliable than that of human driving. It is further recommended to look at the many factors influencing the assessment and consequences of (un)reliability to help determining the level of AV reliability needed in order to make the implementation of AVs a success.

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1. Introduction

The automotive industry has introduced multiple technological innovations over the last decades which led to convenient, safer and more affordable vehicles (Wintersberger et al., 2019). The latest and most significant technological innovation in the automotive industry is that of autonomous vehicles (Bansal & Kockelman, 2017). Autonomous vehicles or AVs could bring many potential benefits by drastically reducing material requirements, air emissions, costs, travel times and accidents as 90% of all vehicle accidents are caused by human errors (Kyriakidis et al., 2015; Li et al., 2018). But in order to take advantage of these potential benefits, people have to adopt and use the AVs. However, it has been determined that people are very reluctant in their intention to use AVs (Asgari & Jin, 2019; Menon et al., 2016; Casley et al., 2013; Bansal & Knockelman, 2017). The study of Menon et al. (2016) found that almost 61.5% of US drivers are unwilling to use AVs and the study of Asgari & Jin (2019) revealed that only 12% of the respondents intended to use AVs in the next ten years.

Davis et al. (1989) stated that the intention to use is the core element in the adoption process of a new technology such as AVs. Peoples low intention to use will therefore be one of the main hurdles for a successful adoption of AVs. For future increasement of the intention to use, an advanced understanding of the factors influencing the intention to use is required. Studies have already determined multiple factors that have proven to influence the intention to use of AVs (Keszey, 2020; Golbabei et al., 2020). Factors such as perceived usefulness and benefits, motivations, innovativeness and trust have proven to positively influence the intention to use AVs. And Factors such as anxiety, driving enjoyment and perceived risks have proven to negatively influence the intention to use AVs. While many factors are already studied, researchers still calls for more studies involving other factors influencing the intention to use AVs (Keszey, 2020; Golbabei et al., 2020; Fagnant & Kockelman, 2014). One factor or variable that seems missing from the theoretical framework regarding the intention to use AVs is that of reliability.

Reliability is a dimension of the total quality of a product and it refers to the level a product will work satisfactory or without failure under stated conditions within a stated period of time (O'connor and Kleyner, 2011). Reliability is already a major factor for conventional vehicle owners, as 55% of the owners selected reliability as the defining factor in their vehicle purchases (J.D. Power, 2016). It has also been proven that when consumers are using unfamiliar innovative products such as AVs, sufficient reliability levels eliminates their doubts or concerns, reduce the perceived risk, and increase the perceived value (Chang et al., 2020). And the perceived risk, doubts and concerns have founded to restrict people in their intention to use AVs (Xu et al., 2018; Liu et at., 2019). This shows that reliability seems to be an important factor to influence people's intention to use AVs and should therefore be investigated.

Additionally, the small amount of literature that included reliability in their studies mainly looked at AV reliability in its entirety (Hancock et al., 2011; Rovira et al., 2019; Kalra & Paddock, 2016). But with the complexity of both the technology AVs possesses (lidars, sensors and navigation) and the whole system around AVs in mind, its reliability should be divided into two types of reliability. The first being the technology reliability which refers to the probability that the driving technology works without failures for a certain period of time. The less likely occurrence of failures that could lead to damage to equipment, injury or loss of life, the more reliable the driving technology is (Verma et al., 2011). The second being the system reliability which refers to the probability that the system around AVs works satisfactory to limit uncertainty about trip time. The less uncertainty about the time taken to travel from the start to the end of a person's journey, the more reliable the system is (Vincent and Hamilton, 2008). As the level of technology and system reliability could be independent of each other, the effect on the intention to use AVs could also differ significantly. More so, AV developers are still improving on the technologies and systems before AVs can be fully implemented in our transportation network. But it may not be possible to establish full reliability levels prior to making them available for public use (Kalra & Paddock, 2016). So in response to the call for more studies involving variables influencing the intention to use AVs, this study will analyse the effects of different levels of technology reliability and system reliability and explore how it affect the intention to use AVs. This leads to the following research question;

What is the effect of technology reliability and system reliability on the intention to use autonomous vehicles?

The social relevance lies in the fact that this study could help AV developers and manufactures to design a vehicle that will be accepted by the public. Knowing the effect of high and low levels of the technology and system reliability on the intention to use could help them overcoming one hurdle in the adoption of AVs. More so, this study will determine how reliability should be proven and communicated to bring AVs to market successfully. This will further help exploiting the enormous potential benefits in terms of safety, emissions and costs to the world. The scientific relevance of this study lies in the increasement of current knowledge of vehicle reliability on the AV adoption process. This is done by dividing reliability into two aspects of technology and system reliability and explore both effects on the intention to use. By which more knowledge will be created in the theoretical framework regarding the intention to use AVs.

By means of both and quantitative and qualitative study, more information is being sought in the realm of AV reliability and the effect of technology reliability and system reliability on the intention to use AVs. The study is structured as followed. Chapter 2 consists of a the theoretical basis of the research, the central concepts and the conceptual frameworks. Chapter 3 consist of the methodology used to assess the effect of the technology and system reliability. Chapter 4 provides the results based on the data analysis of the questionnaire and focus group. In chapters 5, the theoretical and managerial implications are discussed. Chapter 6 elaborates on the limitations of the study. And in chapter 7, the final conclusion of the study is given.

2. Literature review

The first chapter of the study contains the literature review. In this chapter, the theoretical basis of the research is discussed, the central concepts are explained and the relevant literature will be discussed.

2.1 Autonomous vehicles

Autonomous vehicles or AVs are vehicles that are able to drive without the need of an human driver (van den Berg & Verhoef, 2016; Wadud et al., 2016; SAE, 2018). Researchers and manufacturers may have different implementations to enable AVs to drive themselves, but all of them have to ensure the four layers of integrated vehicle control as a minimum requirement (Szalay et al., 2017). These four layers are: the driver interface layer, environment perception layer, trajectory planning layer and trajectory execution layer. The four layers make use of various autonomous driving systems (ADS). These ADS exists of hardware, software and navigation systems to enable functions such as surround view, traffic sign recognition, pedestrian detection and collision avoidance (Browne, 2017). The combined information and data from the ADS enables AVs to safely drive themselves without the need of an human driver (SAE, 2018).

The Society of Automotive Engineers (SAE) (2018) determined six levels of vehicle automation: level 0 refers to a vehicle that has zero automation and the human driver performs all driving tasks; level 1 refers to a vehicle that has minor driving assist technologies; level 2 vehicles have more extensive automated functions but still requires the driver to have full control at all times; level 3 vehicles have the systems to enable self-driving but these systems still require driver inputs from time to time; level 4 vehicles are fully self-driving but only under certain conditions and the driver has the option to take control and level 5 refers to vehicles that can perform all driving tasks under all circumstances and the human occupants are only passengers and are not expected to be available nor have the ability to drive the vehicle at any point during the trip. AVs fall in the most advanced levels 4 and 5 of vehicle automation, as shown in figure 1 (SAE, 2018).

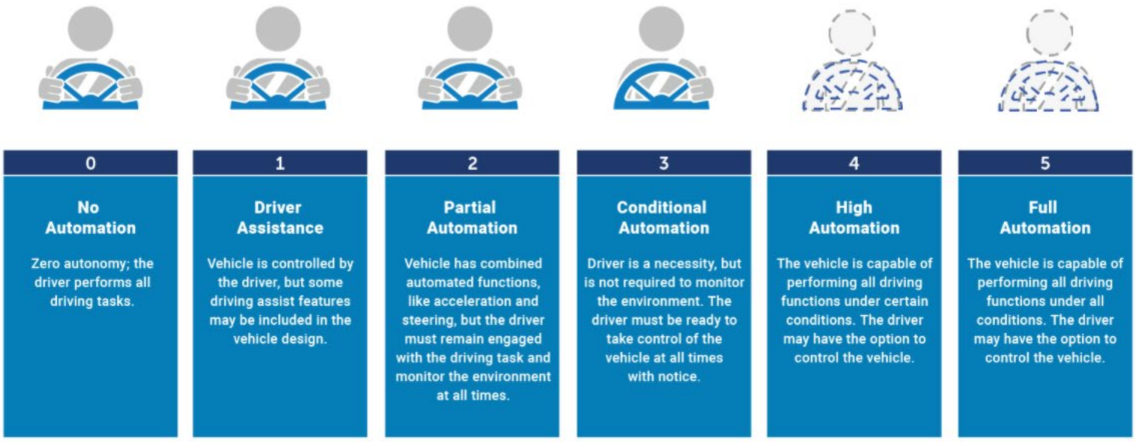

Figure 1. levels of automation by SEA (2018)

Research into automated driving and AVs has been going on for decades. The first attempt towards automated driving dates back as far as the early 1920s (Weber, 2014). But general AV research started from approximately 1980, when university research centres in partnerships with transportation agencies or automotive companies undertook basic studies of autonomous transportation (Anderson et al, 2014; Fenton & Mayhan, 1991). From the year 2004 on, various tests and competitions with partially or fully autonomous vehicles have been executed (Zhao et al., 2018; Wadud et al., 2016; Fagnant & Kockelman, 2014). Some researchers have estimated that by 2030, vehicles with SAE Level 5 will be commonly commercialized and may represent more than 30% of the total automotive fleet (Deloitte, 2018; McKinsey & Co, 2016). While these predictions might be premature, it can be mentioned that the implementation of AVs will take place in the coming decades (Fagnant and Kockelman, 2015). But in order to have a successful implementation of AVs, it is important to know what is needed for people to accept and adopt this new type of automated vehicle transportation.

2.2 Intention to use AVs

While actual adoption of the new technology of AVs can't be measured or determined, because AVs are not yet widely available and therefore can't be adopted. Many studies did look at the intention to use, as this has been determined as the main factor that leads people to actually use and therefore adopt the technology (Davis et al., 1989). Intention to use is often based on Fishbein and Ajzen's (1975) definition of behavioural intention, which refers to the strength of one's intention to perform a specific behaviour. Thus in regards to this study, the intention to use refers to the strength of one's intention to use an AV.

The majority of empirical research on AVs that looked at the adoption of AVs is based on the theoretical models of TAM, UTUAT and TPB as these models helps to predict usage intentions (Dean et al., 2011; Chen & Peng, 2012, Keszey, 2020). The technology acceptance model (TAM) and the unified theory of acceptance & use of technology (UTAUT) are both information systems theories that models how users come to accept and use a technology (Davis, 1986; Venkatish et al., 2003). The theory of planned behaviour (TPB) is a basic psychological framework that explains behavioural intentions in general (Ajzen, 1991). With the use of these three models, it has been tested that people currently are very reluctant in their intention to use AVs (Asgari and Jin, 2019; Menon et al., 2016; Casley et al., 2013; Bansal & Knockelman, 2017). The study of Menon et al (2016) found that almost 61.5% of US drivers are unwilling to use AVs and the study of Asgari and Jin (2019) revealed that only 12% of the respondents intended to use AVs in the next ten years.

With AV knowledge and technological advancements evolving continuously and the implementation of AVs becoming a matter of time, it is necessary to understand which factors are currently known to influence the intention to use AVs. Therefore, the main factors that have been studied and determined to influence the intention to use AVs will be discussed. All these factors can be categorized into four groups of key factors; demographic factors, personality factors, mobility factors and psychological factors.

2.2.1 Demographic factors

Demographic factors are used to define the basic characteristics of a person or population (de Leo & Krysinska, 2008). Demographic factors that influences the intention to use AVs are: gender, age, education level and income. Regarding gender, studies have found that males are likely to be more interested and have a greater intention to use or own AVs than females (Zmud et al., 2016; Kyriakidis et al., 2015; Robertson et al., 2017). The main reason according to those studies is that males are less worried about AVs and feel more confident to let them perform all driving functions. The influence of age on the intention to use varies across different studies. Some studies reported that younger people have a higher intention to use AVs, whereas older people perceive AVs as less helpful and more challenging, and hence they are less interested in using AVs (Robertson et al., 2017; Liu et al., 2019; Schoettle & Sivak, 2014). On the other hand, the study of Nordhoff et al. (2018) concluded the opposite and found a positive relation between age and the intention to use caused by perceptions of receiving more flexible and safer mobility for elderly. The level of education found to positively influence the intention to use (Haboucha et al., 2017; Montoro et al., 2019). Highly educated people tend to show more intention to use AVs as they perceive them to be safer (Pettigrew et al., 2019). It seems that more educated people also have higher expectations, more positive attitudes and thus greater intention to use to AVs due to potentially having a better understanding of new technologies and trusting them more (Schoettle & Sivak, 2014). While it has been founded that willingness to purchase AVs is positively correlated with level of income (Bansal & Kockelman, 2016; Kyriakidis et al., 2015), only one study revealed a significant relationship between income level and the intention to use AVs (Keszey, 2020). However, Hardman et al. (2019) pointed out that "pioneers" or "pro-automated" users are likely to have the highest income, while AV "sceptics" or "laggards" may have the lowest income.

2.2.2 Personality factors

Personality factors or traits reflect basic characteristic dimensions on which people differ (Matthews et al., 2003). There are four personality factors that significantly influence the intention to use AVs: innovativeness, interest, motivation and control. People who have a higher innovativeness tend to be more enthusiastic in their intention to try AVs before others and may perceive greater comfort and safety via actual usage of AVs. And are thus more likely to be early intenders in AV usage (Montoro et al., 2019; Zmud & Sener, 2017; Zmud et al., 2016; Sener et al., 2019). Individuals who are more interested in new technologies appears to have a higher intention to use AVs, as those who are more interested are often more informed about various modes of AV services and their potential benefits (Penmetsa, 2019; Kyriakidis, 2015; König & Neumayr, 2017). On the other hand, studies have also determined that individuals who are more interested but informed with mostly negative information have a decreased intention to use AVs (Sanbonmatsu et al., 2018; Nordhoff et al., 2018). People with (hedonic) motivation, who tend to seek novel, complex, and intense sensations and experiences, and people who enjoy driving, take risks while driving and usually drive alone, generally prefer self-control over their vehicle and are less likely to use AVs (Gkartzonikas & Gkritza, 2019; Haboucha et al., 2017).

2.2.3 Mobility factors

Mobility is defined as the potential for movement and the ability to get from one place to another using one or more modes of transport to meet daily needs (Eltis, 2019). Thus, mobility factors are factors related to vehicle and public transport mobility. Mobility factors that influence the intention to use AVs are: traveling time, driving license, vehicle owners, vehicle accident experience and disability. Regarding traveling time, a greater distance from home to workplace has a negative relationship on the intention to use and vice versa (Keszey, 2020; Hudson et al., 2019). People who drive more frequent and have longer daily travel times are found to be more intended to use AVs for their transportation. This is because those individuals may have to tolerate more fatigue, stress and other disadvantageous factors correlated with long driving tasks (Montoro et al., 2019), as well as the potential decreased travel time if AVs could predict and escape from bottlenecks and drive in platoons (Pakusch et al., 2018; Milakis et al., 2017). Individuals who do not have a driving license are willing to use AVs more frequent than individuals who do have a driving license (Bansal et al., 2016). While current vehicle users and owners seem to be in favour of both shared as well as private AVs. Their intention to use AVs is lower than people who use taxi services or other public transport modes (Sener et al., 2019; Krueger et al., 2016). People that had more conventional vehicle based traffic accidents perceived AVs as safer alternatives for daily transport and have a higher intention to use them (Keszey, 2020; Bansal et al., 2015). And people with disabilities or physical conditions prohibiting them from driving observed to have a higher intention to use AVs (Zmud et al., 2016; Liu et al., 2018; Hassan et al., 2019).

2.2.4 Psychological factors

Psychological factors are related to mental dimensions towards AVs (Nilsson & Kristenson, 2010). There is a wide variety of psychological factors and most of them are interrelated to each other. Following is a summary of the psychological factors that influences the intention to use AVs. The factors of behavioural control and locus of control on the intention to use AVs were investigated in multiple studies (Buckley et al., 2018; Madigan et al., 2017; Brell et al., 2018). It has been indicated that people generally prefer to retain control over the AV rather than completely handing over the control (Schoettle and Sivak, 2014; Nordhoff et al., 2018). Therefore, people who have higher internal locus of control and perceived more behavioural control have a lower intention to use AVs (Lee et al., 2019; Payre et al., 2014). The factors of perceived usefulness and perceived ease of use are positively influencing the intention to use AVs (Zhang et al., 2019; Zmud & Sener, 2017; Nordhoff et al., 2018; Hulse et al., 2018). While Zmud & Sener (2016a) found that a lack of trust in AVs was the reason for 41% of the respondents to not intending to use AVs as their everyday commute mode. It has further been studied that attitudes and trust in AVs considerably increased after initial exposure to AVs (Hartwich et al., 2019). People will intent to use AVs if they could be convinced that they can trust the new technology (Penmetsa et al., 2019; Panagiotopoulos & Dimitrakopoulos, 2018).

Perceived benefits is considered to be the most important psychological factor that positively affect the intention to use AVs (Liu et al., 2018; Xu et al., 2018). The amount of intended AV users is greater if the prospective benefits of AVs have been properly converged

(Nordhoff et al., 2018; Montoro et al., 2019). AVs could reduce the number of accidents drastically as human errors occurring in situations like fatigue, sickness, distraction or under influence of alcohol/drugs would be avoided (Anderson et al., 2014). The reduced number of accidents give also extensive economic benefits by both lowering costs regarding vehicles repairs as well as the costs for hospitals, recovery and rehabilitation (Bagloee et al., 2016). Other benefits of AVs are improved transport dynamization by reducing traffic congestion and lowering transport time, lowering driving stress, enhancing mobility for elderly and disabled people and environmental benefits by increased efficiency and lowering use of energy (Pettigrew et al., 2018a; Bagloee et al., 2016; Fraedrich et al., 2018; Kyriakidis et al., 2015; Buckley et al., 2018; Litman, 2019).

Perceived risks and concerns are considered to be the most important psychological factors that negatively affect the intention to use AVs (Keszey 2020; J.D. Power, 2019; Schoettle & Sivak, 2014; Fagnant & Kockelman, 2015). The public could perceive risks regarding safety issues, hacking issues, ethical issues on personal privacy and data sharing (location or destination tracking), equipment or system failure, interactions with conventional vehicles and other modes of transport and lack of control in a crash situation (Hassan et al., 2019; Hewitt et al., 2019; Haboucha et al., 2017; Pakusch et al., 2018; Shabanpour et al., 2018; Webb, 2019; Silberg et al., 2013). Additionally, the extent to which the usage of an AV will carry risks is found to make people concerned. Safety concerns, data privacy concerns, liability concerns and control concerns were ranked as the biggest concerns of people towards using an AV (Casley et al., 2013; J.D. Power, 2019; Schoettle and Sivak, 2014; Fagnant and Kockelman, 2015; Bansal & Knockelman, 2016; Litman, 2019; Raj et al., 2020; Kyriakidis et al., 2015; Howard & Dai, 2013).

While it is clear that there are many factors that have proven to influence the intention to use AVs, researchers calls to explore other variables that have not been investigated previously but may serve as a critical influencer in the intention to use AVs (Keszey, 2020; Golbabei et al., 2020). One thing that stand out is that all variables that have been proven to influence the intention to use AVs are tied to personal characteristics and none are related to characteristics of the vehicle. Therefore, this study will look at the characteristic of AV reliability and explore how that influences peoples intention to use AVs.

2.3 Autonomous vehicle reliability

Reliability is the consistency of a system's or component's performance according to a predefined set of conditions. The performance relates to required functions and conditions to the environment in which these functions must work. Therefore reliability is often defined as; *"the probability that an item will perform a required function without failure under stated conditions for a stated period of time"* (O'Connor and Kleyner, 2011, p. 1). Reliability is seen as a dimension of the total quality, and the probability of failure is the deciding factor in determining the reliability of the product or system.

The total reliability of AVs will likely consist of the reliability of mechanical parts combined with the reliability of all the technology and software systems. While current designs of autonomous vehicles look a lot like conventional vehicles, it can be assumed that some of the hardware and software parts will be taken over from the conventional vehicles. This could be parts such as the suspension, drivetrain, traction control and anti-lock braking system. All parts that will be taken over from conventional vehicles have been already tested and prove their level of reliability. But, in addition to the parts that are taken over from conventional vehicles, AVs contains more complex and innovative technologies and a new system around AVs which have to prove their own level of reliability.

Most current studies that investigated AV reliability mainly looked at reliability in its entirety (Hancock et al., 2011; Rovira et al., 2019; Kalra & Paddock, 2016). However, this might be too shortcoming if you take the complexity of an AV into account. AVs possesses both new self-driving technologies and an innovative system around the vehicles. And as the self-driving technology and system around the AVs are independent of each other, one might have a high reliability whereas the other might have a low reliability. It is therefore of importance to investigate the reliability of the self-driving technology and system around AVs separately and determine what their individual effect is on the intention to use.

2.3.1 Self-driving technology and reliability

The self-driving technology enables vehicles to drive themselves without the need of any human input. It is the self-driving technology that lets AVs fall in the most advanced levels 4 and 5 of vehicle automation (SAE, 2018). The self-driving technology of AVs consist of the Automated Driving System (ADS), which is a combination of hardware, software and navigation systems (Wintersberger et al., 2019). Regarding the hardware, AVs use multiple sensors to gather information about the vehicle itself and its environment and send the information to the vehicles on-board computer. The speed, movement and position of objects in the environment can be determined by these sensors. AVs are typically built on various types of sensors; inertial navigation systems, light detection and ranging sensor (LIDAR), sound navigation ranging (SONAR) and video cameras. The combined data of the many sensors partially enables autonomous driving (Azmat, 2015; Surden & Williams, 2016). Besides the hardware, the coordinating computer systems or artificial intelligence software systems are also crucial components of AVs driving technology. The software system is capable of organizing and planning all of the AVs' activities. The system connects data from the sensors and the map and uses sophisticated computer algorithms to take the passengers safely to their destination. The software enables the AV to recognize cars, objects, signs, cyclists and pedestrians (Choi et al., 2017; Surden & Williams, 2016; Browne, 2017). Regarding the navigation, AVs counts on digital maps for autonomous driving. The digital maps contains geographical information as coordinates for any point on the road and overhead layouts of other roads. The maps are often manually provided with additional information such as a traffic signals, signs, and traffic lights. This enables AVs to make more accurate driving decisions due to the combination of both preloaded information from digital maps with live sensor information (Choi et al., 2017; Wintersberger et al., 2019). The various sensors and software technologies are shown in figure 2.

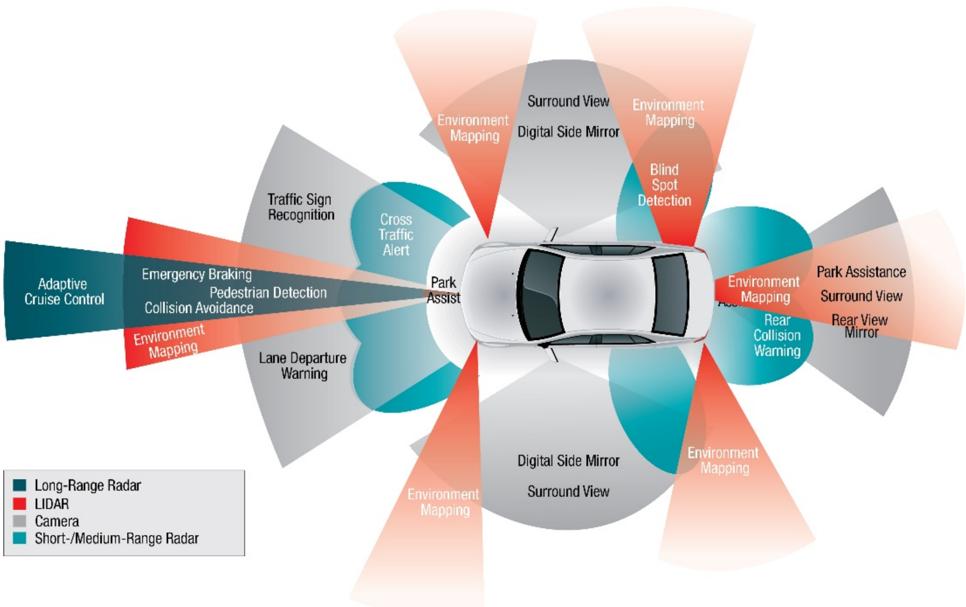

Figure 2. Various hardware and software technologies of an AV by INSIGHTS (2016)

The hardware, software and navigation systems of the driving technology could malfunction or fail. Malfunctions and failures can jeopardise AV passengers and road users in terms of injury or even loss of life. The amount of unknowns in the driving technology is growing as higher levels automation are deployed. These unknows are sparking new concerns and approaches about the level of reliability (Mutschler, 2017). Especially for AVs, which belong to the highest level of automated vehicles (SAE, 2018), the self-driving technology need to work as planned or they will have the risk of causing potential dangerous accidents.

Overall, the self-driving technology reliability or technology reliability refers to the probability that the self-driving technology works without failures for a certain period of time. The less likely occurrence of failures that could lead to potential damage to equipment, injury or loss of life, the more reliable the driving technology is (Verma et al., 2011). The reliability of the ADS must be designed into the vehicles and tested during the development phase (Stimson, 2018). When reliability is not designed into the self-driving technology of the AV, its existence could be problematic. Especially when the lack of reliability restricts people from using the AV. In the beginning of AV development, the testing of the ADS (technology, software and navigation) was largely done by participating in AV challenges. These challenges were specially designed to test the driving technology in real world conditions, as the vehicles were otherwise not allowed to drive on the public streets. The challenges allowed AV developers to test their vehicles for many miles under different conditions and environments. In 2004, 15 teams joint the first AV challenge that took place in the Mojave Desert region of the USA. The main goal of the challenge was to pass through 240 km of desert. While no team was able to complete the task in the first year, five teams were able to complete the task three years later (DARPA, n.d.). The AVs needed to be capable of driving in traffic, performing complex manoeuvres such as merging, passing, parking, and negotiating intersections. From then on, more challenges took place to test the performance and reliability of AVs' driving technology. In September 2011, a free autonomous vehicle trail named "Made in Germany" was held around the University complex of Berlin. During this journey, the AV travelled nearly 20 kilometres, which includes 46 traffic lights and two island rings. In July 2013, an AV developed by the Artificial Vision and Intelligent Systems Laboratory (VisLab) of the Parma University in Italy, drove around the old section of Parma city without any human participation. The AV passed successfully the single two-lane and roundabout, recognized the traffic lights, pedestrians crossing the road, man-made raised pavement conditions, etc. (Zhao, et al., 2018). Google, which was one of the leading companies in AV development, demonstrated their first vehicle in 2012 (Wadud et al., 2016). By the end of 2014, their project contained eight AVs and they have been tested on more than 700,000 kilometres. The AVs had to manoeuvre on different driving roads covering urban, highway, mountainous road and various other roads (Fagnant & Kockelman, 2014). Overall, developers and manufactures are trying their best to test and to convince people of the reliability and safety of these automated driving technologies.

Despite the efforts of developers and manufactures to convince people of the technology reliability, questions still arise around the reliability and safety of AVs (Waldrop, 2015). Reliability must be further verified with warranty data from real world usage to define the actual reliability of AVs (Stimson, 2018; Meeker et al., 2003; Condra, 1993). The study of Kalra & Paddock (2016) looked at the level of technology reliability in terms of failure and safety. They investigated how many miles and years are needed to demonstrate a certain level of technology reliability. They asked the question "How many miles (years) would AVs have to be driven to demonstrate with 95% confidence their failure rate to within 20% of the true rate of 1.09 fatalities per 100 million miles?" To clarify, the current failure rate of human driving is 1.09 fatalities per 100 million miles. The results were shown in number of years it would take to drive the needed miles with a fleet of 100 autonomous vehicles driving 24 hours a day, 365 days a year, at an average speed of 25 miles per hour. The answer is 8.8 billion miles! This would take 400 years with the fleet of AVs that has been described above. The following was said in response to the results.

Our results confirm and quantify that developers of this technology and third-party testers cannot drive their way to safety. […] it may not be possible to establish the safety of autonomous vehicles prior to making them available for public use (Kalra & Paddock, 2016, p. 191).

It can be concluded that in the case of AVs, the technology reliability can't be guaranteed before the commercialisation of AVs. Only after AVs are commercialised, enough data can be acquired to strongly ensure a level of technology reliability, as the aspect of environment and time in which the AV operates is a critical factor in evaluating the reliability of each innovative product (Meeker et al., 2003; Condra, 1993). But to acquire the necessary data from commercialized AVs, people need to use and thus have the intention to use AVs in the first place. Therefore, the first main purpose of this study is to determine the effect of high and low levels of technology reliability and explores how it affects the intention to use AVs.

2.3.2 System around AVs and reliability

In addition to the self-driving technology, the implementation of AVs requires also a new system around AVs. The motive of AV development is to take advantage of the economic, environmental and safety benefits that arise by replacing the human driver (Bansal & Kockelman, 2017). This requires the implementation of a system that enables AVs to meet the requirements of current vehicle usage, by which it becomes unnecessary for most individuals to own a conventional vehicle. The system of AVs should make this possible by enable people to demand an AV from a fleet using a smartphone application and being confident that it will arrive within minutes. By which they can use that AV for their needs and when they are done, the AV can be demanded by others (Hancock et al., 2019). This system is called the Automated Mobility on Demand or AMoD (Pavone, 2016; Beiker, 2016) (see figure 3). The image shows, in a simplified form, how an AMoD system works.

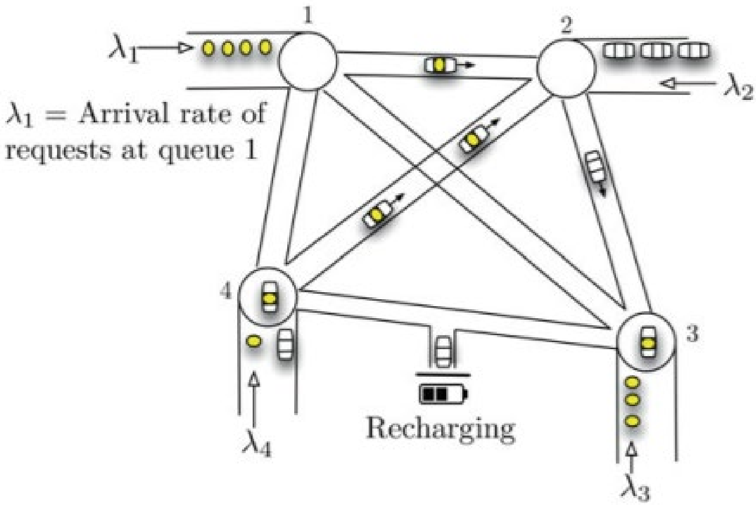

Figure 3. A queueing model of an AMoD system entails by Pavone (2016). The image shows an dynamical process that generates "transportation requests" (yellow dots) at queues and AVs (represented by small car icons).

When someone wants to use an AV, a transportation request arrives at the system. The system then brings the nearest available AV to the requested location. When there are more requests than AVs, the transportation requests queue up within the system. The reliability of the system includes the availability of vehicles upon the request's arrival (i.e., the probability that at least one vehicle is available to provide immediate service) or average wait times to receive service (Pavone, 2016). A reliable system around AVs is able to allocate AVs to the transportation requests and take the users to their destinations as fast or efficient as possible to minimize wait and trip times. In order for the system described above to work properly, it needs to consist of certain aspects. These aspects are: transportation requests or demand application, charging stations and minimal amount of AVs (Pavone, 2016).

The transportation request will likely work via an demand application on a smartphone. In order for the demand application to work smoothly, it has to be free of issues or glitches and highly secured for hacking attacks. When a well-working demand application can't always be guaranteed, a back-up application must be developed in case the first application does not work properly. The charging stations within the system around AVs must be developed and build. While AVs have the ability to drive themselves without the need of a human driver, they do not have the ability to charge themselves at current charging stations (Pavone, 2016). Most charging stations require driver or passenger to step out of the vehicle and manually connect the vehicle to the charge station. In the case an AV is empty and has to be recharged, it must be able to do this without the need of its passengers. Therefore, charging stations must be developed and build by which AVs can recharge themselves automatically.

In order to have a system that can provide the demander a vehicle within a certain time frame, a minimal amount of AVs are needed. Spieser et al. (2014) conducted a case study about an hypothetical deployment of an AMoD system to meet the personal mobility need of the entire population of Singapore. A total of 92,693 AVs are required to ensure the transportation demand remains bounded. Consider that at 1,144,400 households in Singapore, there would be roughly one AV every 12.3 households. However, waiting times at this amount would be unacceptably high. To ensure acceptable quality of the system, the fleet size needs to increase. With about 200,000 AVs, availability is about 90 % on average, but maximum waiting times during peak hours is more than 60 minutes. From around 300,000 AVs, availability is about 95 % on average and peak waiting times are reduced to less than 15 min (see figure 4).

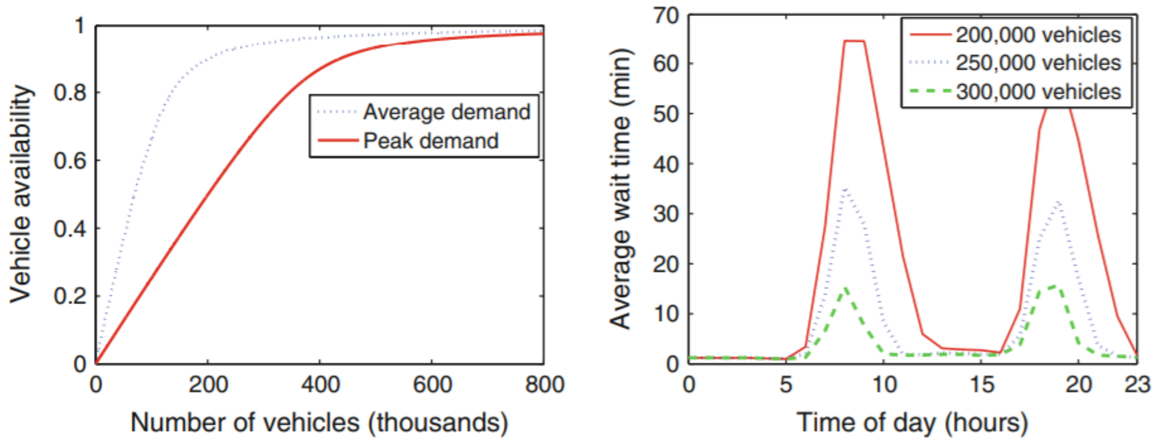

Figure 4. Case study of Singapore. ***Left figure*****; performance curve showing the availability of AVs versus the size of the system for both average demand (2–3 pm) and peak demand (7–8 am).** ***Right figure*****; average waiting times over the course of a day, for systems of different sizes (Pavone, 2016).**

The results of the study of Spieser et al. (2014) implies that if AVs are going to meet the personal mobility needs of the entire population of big countries or even continents, millions of AVs are needed. But to put these numbers into perspective, 779,890 passenger vehicles were operating in Singapore in 2011 (Land Transport Authority, 2012). Hence, the study suggest that only roughly 1/3, of the current number of passenger vehicles, in AVs are needed to meet the personal mobility need of the entire population of Singapore. This will result in many benefits such as less material use, emissions, traffic jams, etc.

Vincent and Hamilton (2008) defined the reliability of the system around AVs or system reliability, within the public transport system context, as the following;

Uncertainty in the time taken to travel from the start to the end of a person's journey. This uncertainty means that a person must make some allowance in the timing of their journey to allow for this uncertainty so that they can still reach the end within a desirable time band (Vincent & Hamilton, 2008, p.14).

Therefore, the reliability of the system around AVs refers to the probability that the system around AVs works satisfactory to limit uncertainty about trip time. The less uncertainty about the time taken to travel from the start to the end of a person's journey, the more reliable the system is (Vincent and Hamilton, 2008). During the introduction of electric vehicles (EVs) it has become more apparent that a reliable system around AVs is important. To clarify, the following paragraph gives a short description and problematization of the implementation of electric vehicles and the importance of a reliable system around EVs.

In 2012, Tesla was the first automotive company that commercialised EVs on a large scale with the introduction of the model S (Tesla, 2012). The commercialisation of Tesla involved, besides the vehicle itself, also the implementation of a whole system around EVs. One aspect of this new system for EVs were the charging stations. A network of charging stations did not exist and thus had to be build. It took many years to build a bullet proof network of charging stations. The low amount of charging stations in the meantime resulted in multiple issues regarding the usage of Tesla's vehicles. People could not drive for long distances and users had problems due to few possibilities to (re)charge the vehicles. In 2019, there were around 50 Tesla's waiting to be charged at world's biggest charging station. Driving to another station was not an option as not all fuel station had charging station, and other stations where the vehicle could be charged were situated too far. It would therefore take the last vehicle in the line more than an hour to charge back to full (Machielvdd, 2019; Priest 2020).

This example shows that there is more needed than the technology reliability of the vehicle itself. A well working and reliable system around a new type of vehicle is also critical for its usage. In the case of an AV, the reliability of the system around AVs is likely to be even more important than that of EVs.

If one aspect of the system does not perform it intended function, the overall systems reliability will be at stake. While some system functions might be more important than others, the total combination of system functions will determine whether the system around AVs is reliable or not. Therefore, all aspects within the system have to systematically work together to ensure a level of system reliability. The lower the level of system reliability, the higher the probability that delays occur. Nevertheless, as with many complex innovative systems, full reliability of the system around AVs could be hard to reach. Thus, the second main purpose of this study is to determine the effect of low and high levels of system reliability on the intention to use AVs.

2.4 Conceptual framework

It has been proven that when people are using highly unfamiliar products such as AVs, reliability can eliminate their doubts, reduce the perceived risk, and increase the perceived value (Chang et al., 2020). And perceived risk, concerns and doubts are important factors in the intention to use AVs (Xu et al., 2018; Liu et at., 2019). With current vehicle users, reliability is already a major factor as 55% of the owners selected reliability as the defining factor in their vehicle purchases (J.D. Power, 2016). This indicates that reliability is an important factor to influence people's intention to use AVs and is worth investigating.

Regarding the self-driving technology reliability or technology reliability, a low reliability level could have multiple consequences. The AVs could have difficulties in recognizing cars, object and pedestrians in its surroundings (Azmat, 2015; Surden & Williams, 2016), with potential damage to equipment, injury or loss of life as a result. The AVs could have problems in making accurate driving decisions which, for instance, could lead the vehicles driving in closed roads, wrong directions or even of the road (Choi et al., 2017). The AVs could fully stop driving as the mechanism of gas, brake and steer could have malfunctions and stop working, which will be dangerous as they could stop in hazard situations such as highways. Overall, the low reliability will likely increased safety risks and concerns about failure of the self-driving technology will likely reduces the intention to use. And safety issues, interactions with other modes of transport and lack of control in a crash situation have already found to be key factors that negatively influence the intention to use (Golbabei et al., 2020; Keszey 2020; Schoettle & Sivak, 2014; Fagnant & Kockelman, 2015;). On the other side, high technology reliability has the opposite effect. High technology reliability will decrease safety risks and concerns among potential AV users. Hence, high technology reliability will likely influence the intention to use in a positive manor. It has also been proven that high technology reliability results in a higher level of trust in new technologies (Hancock et al., 2011; Hengstler et al., 2016) and the variable of trust is a key factor that positively influences the intention to use AVs (Choi & Ji, 2015; Ward et al., 2017; Zhang et al., 2020). Therefore, the first hypothesis of this study is:

H1: Technology reliability has a positive effect on the intention to use AVs.

Regarding the system reliability, a low reliability level increases the probability in failures regarding the demanding application, charging and minimal amount of AVs (Pavone, 2016). The demand application could malfunction or stop working which excludes users from demanding and directly inhibits using the AV. The system could have problems recognizing the users location which means users need to change locations. The AVs could have problems during charging which results in the vehicles running out of energy. All these issues prevent the system to work as intended and result in three types of delaying consequences. The arrival, departure and in-vehicle time delays. The delayed departure time causes AVs to arrive late at the users location and forces the user to demand the AV earlier. And the delayed arrival time causes users to arrive later at their destination than scheduled. Not knowing when the AV is going to departure and arrive increases concern and anxiety caused by total trip time uncertainty. The in-vehicle-time delays also increases concern and anxiety caused by uncertainty about how long they will have to spend in the AV and also impacts how late they are arriving at their destination. Hence, low system reliability results in higher probability of delays, more uncertainty and concerns about the total trip times. Concerns have found to be a main factor that negatively influence the intention to use. Additionally, delays could also reduce factors such as performance expectancy and perceived usefulness, that have proven to positively affect behavioural intention to use (Keszey 2020; Chen, 2006). On the other hand, high system reliability results in lower probability of delays and less uncertainty and concerns. High system reliability will thus likely lead to a higher intention to use AVs. Therefore, the second hypothesis of this study is:

H2: System reliability has a positive effect on the intention to use AVs.

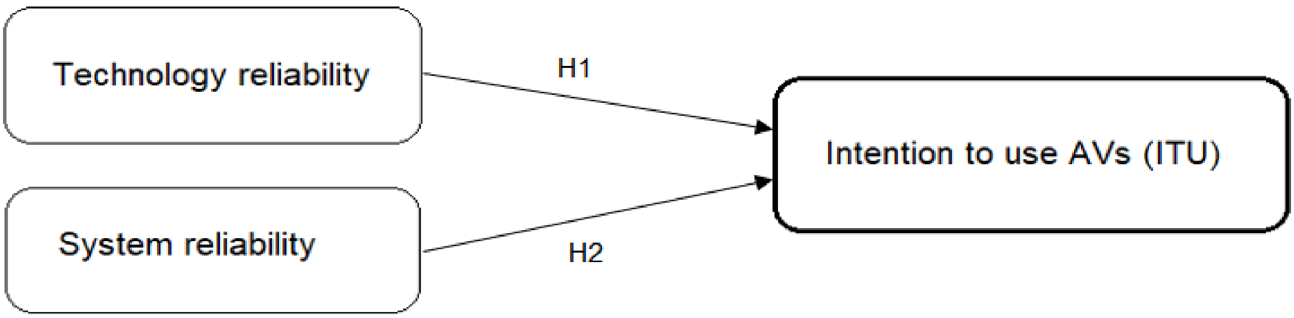

Figure 5. Conceptual framework of relationship postulated in both hypothesis.

3. Methodology

3.1 Research method

The research was done by means of a quantitative research method on the basis of an 2x2 between-subject experimental research design and qualitative research method through a focus group. The quantitative research method is used to test the hypothesises. Two independent variables of technology reliability & system reliability and one dependent variable of the intention-to-use were tested. The 2x2 between-subject design enabled the researcher to use different scenarios to manipulated the two independent variables and explores how they affects the intention to use AVs. The scenarios consisted of a variation in the technology reliability (high vs low) and a variation in the system reliability (high vs low). This experimental design ensures that all construct are measured consequently and that there is full control over the manipulation and variance in the research (Charness et al., 2012).

A qualitative study is subsequently added to explore the subject of reliability, by taking more context into account and therefore create more dept into the subject of reliability. The focus group method is chosen as it can be can be especially useful in exploratory research (Stewart & Shamdasani, 2014). It enables and encourage participants to ask each other questions, exchange experiences and give responses to each other's experiences and opinions. The focus group is therefore a suitable data collection method for investigating the participants opinions, examining not only what they think but also how and why they think that. The interaction between participants that takes place in this group discussion helps to facilitate opinions that would not have developed in an individual interview. The resulting aim of the qualitative research is a further conceptual development of reliability, to examine what participants think of (AV) reliability, how they dealt or going to deal with reliability issues and wants developers to prove and communicate the reliability of AVs.

3.2 Data collection

Data for this study was collected via an online questionnaire that participants could reach via a link and a focus group that was organised by the researcher. In terms of the online questionnaire, a review of the AV literature was used to identify appropriate measures for the constructs. Items were rewritten as necessary to fit the context of this study. The measured instrument of this study was divided into two sections in the online questionnaire. The first part of the questionnaire contained the experimental phase regarding the questions about the three main constructs of technology reliability, system reliability and intention to use the AV. Multi-items were used to measure each construct (table 3). The experimental phase first showed each participant one of four versions of a newspaper article for a full automated vehicle called ‘WAYMO’. The newspaper articles used in this study contained the image and title of an actual published newspaper about WAYMO, with the name of the actual former CEO and general information about the autonomous or self-driving vehicle (Krabbendam, 2018). This first small paragraph of the newspaper articles were identical in every case. The variation was in the descriptive nature of the scenarios about WAYMO’s reliability. There were four scenarios which presented the participants with different information about WAYMO’s levels of technology reliability and system reliability. The variations were “high technology reliability versus low technology reliability” and “high system reliability versus low system reliability”. Appendix 1 includes the four newspaper articles used in the survey (Dutch version). Participants in the experiment were exposed to only one newspaper article containing one of the four scenarios:

1. High technology reliability x high system reliability
2. High technology reliability x low system reliability
3. Low technology reliability x high system reliability
4. Low technology reliability x low system reliability

After participants read one of the four newspaper articles, they were asked to answer questions about the construct of technology reliability, the construct of system reliability and the construct of intention to use. Each construct was measured with multiple items using seven-point Likert scales (table 3). The second part of the questionnaire contained general questions relating to demographic information about the participants. For a full view on the questionnaire, see appendix 2.

The focus group was set up on the basis of the literature review and the results of the quantitative study. The main focus of the focus group was to start a discussion and gain more knowledge for a further conceptual development of reliability. The focus group was structured in an introductory and constructive way, starting with a short introduction of the main research and what would be done with the results. The focus group consisted of four themes with questions and statements which served as the starting points of the discussions. If necessary, a short explanation was given prior to the questions or statements. The themes were ranked from general to specific. All questions and statements were ‘open’ and formulated in an understandable manner. The role of the researcher was to stimulate and facilitate the discussion and only intervene in a controlling way; when the discussions deviated too much from the topic, when people did not fully understand each other, when someone was interrupted by surprise and making sure everyone could have their say (Van Assema et al., 1992; Stewart & Shamdasani, 2014). For a full review of the themes, questions and statements of the focus group, see appendix 3.

3.3 Selection of participants

The participants for the pre-tests were selected within the social network (family and friends) of the researcher. This sample can thus be seen as a convenience sample (Martínez-Mesa et al., 2016). The participants for the main experimental study were selected through the means of both the student network at the Radboud University of Nijmegen (RU) and employee network of the Wageningen University & Research (WUR). These networks have been chosen as they stood close to the researcher, enable the study to reach a sufficient number of participants and to obtain variation in demographic variables. This will help to increase external validity by being able to generalize the results of the study. The participants were contacted though email or WhatsApp, and they were free to decide whether and when they wanted to fill in the questionnaire. The distribution of the participants to one of the four scenarios is done with the usage of the randomisation setting in the Qualtrics program. The advanced question randomisation was used to randomly insert one of the four newspaper articles in each questionnaire. The newspaper articles were evenly displayed across all participants to ensure that each scenario reached a minimum of 20 responses. The sample of the main study can be seen as simple random selection within RU students and WUR employees (Martínez-Mesa et al., 2016). Conclusively, a total of three different groups consisting of two pre-test groups and the main study group were selected for the quantitative study.

For the qualitative study of the focus group, the selection of the respondents was carried out by means of a select sample. First, it was important that participants would regularly travel by car and/or public transport to gain more relevant information related to the studied subjects. The aim was to gather a focus group that is homogenous of nature in terms of characteristics such as age, educational attainment and social status. This increased the likelihood of participants willing to give their opinion in an environment with 'similar' people (Van Assema et al., 1992). However, heterogeneity in terms of educational backgrounds is chosen to increase the probability of different opinions. These different opinions urged participants to think about the other perspectives and can lead to more interesting discussions (Stewart & Shamdasani, 2014). Conclusively, the studied focus group consisted of a total of 8 respondents.

3.4 Data analysis

In order to analyse the data and get useful results to obtain an answer on the hypothesis, the analysis method of 2x2 Factorial Between Subjects ANOVA was used for this research. This type of analysis enables variation in the description of the independent variables by which could be determined whether the level of technology reliability and system reliability had a significant effect on the intention to use AVs (Coleman, 2000). The description of independent variables consisted of the technology reliability and system reliability, each with two reliability levels (high vs low). Both hypotheses (H1 & H2) were tested on the basis of the 2x2 Factorial Between Subjects ANOVA analysis. The focus group was recorded via three mobile phones to make sure everything that was said was recorded well, as the room was too large for one mobile phone to record all voices clearly. These recordings have been transcribed and coded openly, axially and selectively to allow for comparison of the results (Benders, 2019).

3.5 Measures

The construct of intention to use AVs refers to the strength of one's intention to use an AV (Fishbein & Azjen, 1975). This construct was measured by three different items derived from a well-established scale previously used to study the intention to use regarding vehicle usage (Han et al., 2010). The construct was measured through three items concerning; (1) the willingness to use, (2) the plan to use and (3) effort to use. The construct of technology reliability refers to the level of perceived technology reliability, through the probability that failure of the self-driving technology will occur (Verma et al., 2011). The measurement items were based on a combination of the factors of product reliability (probability, durability, dependability, quality over time and availability to perform a function) and reliability and safety engineering (O'Connor, 2002; ASQ, 2021);. The construct was measured through four items; (1) probability of accidents occur, (2) durability of driving performance, (3) dependability of detection systems and (4) quality of driving technology. The constructs of system reliability refers to the level of perceived system reliability, trough the probability that the system around AVs malfunctions and increases uncertainty about trip time (Vincent & Hamilton, 2008). They divided the uncertainty about trip time, occurring from the system, into three different aspect; arrival time, departure time and in-vehicle-time. The four measurement items for the system reliability were based on these three aspects; (1) accurate departure time, (2) system influencing in-vehicle time, (3) accurate arrival time and (4) delays due to system inconsistency.

The measurement items of technology and system reliability as well as the scenario's in the newspaper articles did not (fully) exist or were adjusted. To check whether the scenarios and items had been effective and measured valid results, a pre-test and factor analysis have been done before actually conducting the main study. The first pre-test from a convenience sample of 16 respondents showed the measurement items (in combination with the scenarios) were not suitable for the study. Therefore, the scenarios were adjusted to better fit the constructs of technology and system reliability and question items 2, 3, 6 and 7 were rewritten before the second pre-test was conducted.

The second per-test from an convenience sample of 18 respondents showed sufficient results (determinant = 0,11; KMO = ,774; Bartlett's = sign. $p < 0.05$). The construct reliability was assessed to validate the results of the factor analysis. Cronbach's Alpha tests were conducted for each of the two factors (Hair et al., 2018). The analysis revealed acceptable results for both factors (Cronbach's Alpha = ,889 and ,857) which are both above the desired 0.7 (Hair et al., 2014). In the assessment of convergent reliability, all loadings were significant and larger than 0.7 (Hair et al., 2017). And a second aspect of convergent reliability refers to the average variance extracted (AVE). For both factors, The AVE scores exceeded the minimum threshold of 0.5. The discriminant validity was assessed by comparing the means of both AVE and the correlation^2. The variance extracted was larger than the corelation^2 (,725 > ,0096) and hence discriminant validity was established. For all relevant data, see tables 1 and 2.

Table 1. Factor analysis (results from second pre-test)

	Technology reliability	System reliability
Item 1. The driving technology increases the risk of (fatal) accidents. (-)	,843 ***	,077 ns
Item 2. The driving performance remains the same over the entire period of use.	,837 ***	-,022 ns
Item 3. The vehicles detect road signs and road users without any problems in all weather conditions.	,905 ***	-,107 ns
Item 4. The driving technology makes driving safer than traditional human driving.	,896 ***	,067 ns
Item 5. The actual departure time from location can always be accurately determined.	,101 ns	,793 ***
Item 6. The real travel time may differ from the stated travel time due to the system. (-)	-,156 ns	,818 ***
Item 7. The actual arrival time at the final destination can always be accurately determined.	,041 ns	,875 ***
Item 8. Inconsistency of the system leads to delays. (-)	,029 ns	,839 ***

Factor loadings per item: *** = significant ($p < 0.05$) & ns = not significant
Determinant = ,011; KMO = ,774; Bartlett's = sign. ,000

Table 2. Criteria for assessing convergent reliability, discriminant validity and construct reliability

Construct	Items	Loadings	AVE	Correlation^2	Cronbach's Alpha
Technology reliability	TR1	,843	,758	,0096	,889
	TR2	,837			
	TR3	,905			
	TR4	,896			
System reliability	SR1	,793	,692		,857
	SR2	,818			
	SR3	,875			
	SR4	,839			

Note: loadings and AVE refer to convergent reliability (AVE > ,50); AVE and correlation square refer to discriminant validity (Mean AVE > ,0096); Cronbach's Alpha refers to construct reliability (> ,70).

The questionnaire was administered in Dutch, and therefore a translation from English into Dutch was made of the questions that were copied from English. The translation is done by the researcher with the use of the backward translation approach (Brislin, 1970). Following this translation procedure, a comparison of the initial and the back-translated questionnaires with the help of other students is done to check for content changes and mistranslations. For a full review of the questionnaire, see appendix 2.

The operationalisation consist of Table 3, which shows the key constructs and definitions, the measurement scales & items and where they are adapted from. The measurement scales of the 7-point Likert scale ranged from strongly disagree to strongly agree.

Table 3. Operationalisation of constructs, measurement scale and items

Construct & Definition	Scale / Item	Adapted from
Technology Reliability *perceived technology reliability, through the probability that failure of the self-driving technology will occur (Verma et al., 2011).*	*7-point Likert scale* **TR1.** The driving technology increases the risk of (fatal) accidents. (-) **TR2.** The driving performance remains the same over the entire period of use. **TR3.** The vehicles detect road signs and road users without any problems in all weather conditions. **TR4.** The driving technology makes driving safer than traditional human driving.	ASQ (2021) & O'Connor (2002)
System Reliability *Perceived system Reliability, trough the probability that the system around AVs malfunctions and*	*7-point Likert scale* **SR1.** The actual departure time from location can always be accurately determined. **SR2.** The real travel time may differ from the stated travel time due to the system. (-)	Vincent & Hamilton (2008)

increases uncertainty about trip time (Vincent & Hamilton, 2008)	**SR3.** The actual arrival time at the final destination can always be accurately determined. **SR4.** Inconsistency of the system leads to delays. (-)	
Intention to use (AVs) *The strength of one's intention to use an AV (Fishbein and Ajzen's, 1975)*	*7-point Likert scale* **ITU1.** Assuming I have access to the self-driving vehicles, I am willing to use them. **ITU2.** I plan to use the self-driving vehicles. **ITU3.** I will make an effort to use these self-driving vehicles.	Han et al. (2010)

(-) Reverse scale item

Measures of the focus group was done by building a route of questions addressing five themes; the concept of reliability, reliability within transport, technology reliability, system reliability and prove & communication of reliability. The question route was built with the intention to initiate a discussion about each theme. The discussions were then facilitated to go deeper into the how and why of the participants opinions. Therefore, both the themes itself and the questions within the themes went from general to more specific. Almost all questions and statements were 'open' and have been tried to formulate in an understandable manner. The overview in table 4 shows the conceptualisation of the central themes in this qualitative study.

Table 4. Operationalisation of focus group main questions

Dimension	Indicator	Question
Concept of reliability	Term opinion Assessment Importance	What do you think when you hear the word 'reliability'? What makes you consider a product/service to be reliable? How important is reliability in a product/service? Which factors does influence this importance?
Reliability within transport	Assessment Experience Dealing with Opinion and behaviour	How do you asses the reliability of cars / public transport? What is your experience with unreliable cars / public transport? How did you deal with unreliability? How has this influenced or changed your opinions and behaviour regarding the intention to use?
Technology reliability	Assessment Importance Consequences Comparison Acceptance	How do you asses the reliability of self-driving technology? How important is a well-functioning self-driving technology? What happens if this technology shows defects? How does this affect your use of self-driving vehicles? How can it be more positive with other high automated technologies? What would be a minimum acceptable level?

System reliability	Assessment Importance Consequences Comparison Acceptance	How do you asses the reliability of the system / travel time? When is variation in travel time with a self-driving vehicle a problem? What effect does delay in daily travel have on you? What different effect does it have regarding public transport users and cars users? How can we make delays less of an issue / creating acceptance?
Prove & communication of AV reliability	Prove Communication	How do you feel about testing the self-driving vehicles on the street? How should reliability tests be facilitated? How should manufacturers communicate reliability to the public? What else can organizations do to convince the public of AVs reliability?

3.6 Validity and Reliability

Validity and reliability are important in any scientific research (Vennix, 2011). For the purpose of validity regarding the quantitative study, the constructs and items have been based on established literature and questionnaires whenever possible. However, the items of the technology reliability and system reliability could not be fully based on existing questionnaires. A pre-test and factor analysis were done to determine whether the items measured the constructs correctly (see subchapter 4.5 measures and table 1 & 2). The descriptions of the scenarios have also been developed by the researcher. However, due to not having a control group, it has not been established in what way the measures were actually the result of the manipulation in the scenarios. This means that the internal validity is lower than aimed for. The external validity has been improved by selecting a variation of participants to enable better generalization of the results of the study. But, full generalization of the results should be done with high cautiousness. For the purpose of validity regarding the qualitative study, the focus group was drawn up on the basis of the literature and the outcome of the quantitative study. Since this study concerns a qualitative study with a limited number of respondents, it is difficult to generalize the results. The external validity is therefore less applicable in this study.

Reliability concerns the consistency and accuracy of the measurement procedure or experiment (Vennix, 2011). The reliability of the measures has been ensured by using the same questions for all respondents. Reliability has also been ensured by homogeneity between different items within the constructs to produce equivalent results. The methods used in the data analysis have further tried to reduce biases in the dataset and increase the reliability (table 1 & 2). Besides the data analysis, the construct reliability is also tried to increase by giving the definition of the construct in the questionnaire (appendix 2), so respondents had a more clear idea on what the questions resembled. The same terminology of the definition of technology and system reliability is used within the focus group to increase the construct reliability. The coding of the focus group was also done by one researcher himself and therefore consistent. By means of triangulation, the internal reliability has been further increased. Although, it must be mentioned that the convenience sample approach of the pre-tests has an effect on the reliability of this research, a repeat of the research by another researcher with a different network and social circle could yield different results.

3.7 Research ethics

To carry out this study, the five principles for research ethics of APA's Science Directorate have been covered as much as possible (Smith, 2003). The purpose of the research, expected duration and procedure of the questionnaire have been given at the beginning of survey. It has been made clear that the participation is completely voluntary and the participants were free to withdraw at any time without consequences in doing so. In case questions arises, the participants had the possibility to contact the researcher by mail or phone. Furthermore, the data treatment details were explaining in the form that personal or confidential data were not used and participation was fully anonymous to remove potential risks for the integrity of our participants. At least, the date was confidential processed and the results are only used in the context of this Master thesis. All these aspects were provided to the participants before they completed the questionnaire.

4. Results

4.1 Results of quantitative study (questionnaire)

A 2x2 between subject ANOVA was performed to examine the main effects of technology reliability and system reliability on the intention to use AVs (ITU). The main study contained a total of 112 responses. The total dataset had three missing values which have been removed. Additionally, more data have been removed due to the manipulation check which have been tested via the 4 items of technology reliability and 4 items of system reliability (tables 1 & 3). Respondents who measured low reliability levels to be high (Mean > 4) and high reliability levels to be low (Mean < 4) have been removed from the dataset. Therefore, the following data analysis is based on the valid results of 93 respondents.

4.1.1 General characteristics of respondents

With regard to the respondents personal characterises a total of 41 men and 52 woman have participated in the main questionnaire. The age of the respondents is distributed as shown in figure 6 below.

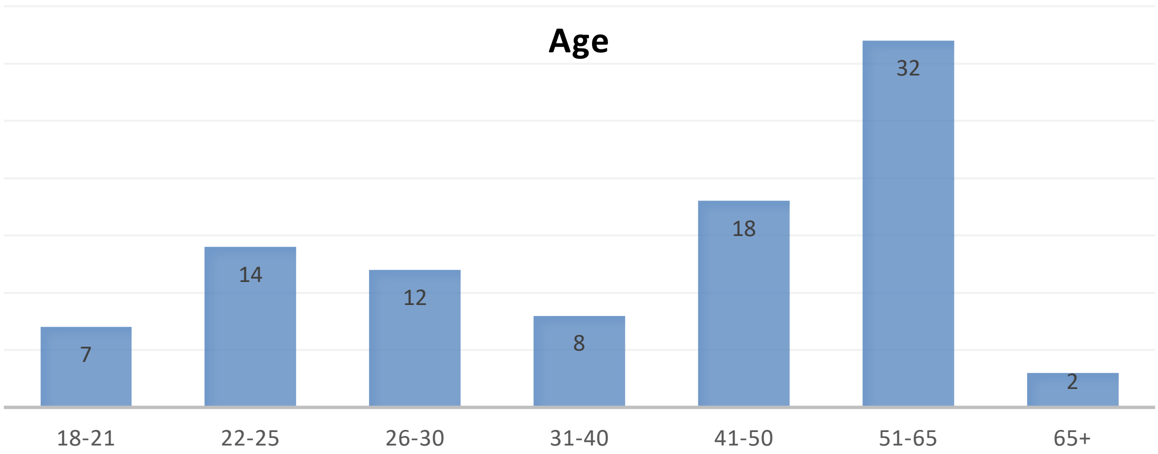

Figure 6. Distribution of respondents age

Regarding the educational level, the majority of the respondents have WO / University as highest ranking educational level (59), followed by HBO (23), MBO (5) and secondary education (6). Most of the respondents are employed (68), followed by student (18), self-employed (3), unemployed (1) and people having a job other than the choices above (3). With regard to the respondents characteristics of having a driving license the fast majority of the respondents have had a driver's license for more than 10 years (55), followed by 6-10 years

(12), 2-5 years (12), only one year (4) an no driver's license (10). The percentage of car usage among the respondents is distributed as followed: daily (11,8%), few times a week (36,6%), once a week (18,3%), once to a few times a month (17,2%) and less frequent (16,1%). The percentage of public transport usage among the respondents is distributed as followed: daily (2,2%), few times a week (17,2%), once a week (7,5%), once to a few times a month (18,3%) and less frequent (54,8%). The majority of the respondents uses public transport less than once a month.

4.1.2 Main effects technology reliability & system reliability on ITU

An 2x2 subject design ANOVA with respect to the intention to use AVs (ITU) scores was conducted to measure whether or not the level of technology reliability and system reliability had an effect on the ITU. The first hypothesis (H1) was about the effect of technology reliability on the ITU. To be precise, if an increase in the level of the technology reliability leads to an increase in the intention to use AVs. A total of 45 respondents have answered the questionnaire according to a low technology reliability and 58 respondents according to a high technology reliability. The outcome was that H1 was accepted ($F(1,89) = 19{,}095$; $p < 0{,}05$; $PE^2 = {,}177$). The mean ITU score of low technology reliability ($M = 2{,}978$; $SD = 1{,}38$) did differ significantly from the mean of high technology reliability ($M = 4{,}287$; $SD = 1{,}50$), the level of technology reliability has an positive effect on the ITU (figure 7 and table 5). The second hypothesis was about the effect of system reliability on the ITU. To be precise, if an increase in the level of vehicles system reliability leads to an increase in the intention to use AVs. A total of 45 respondents have answered the questionnaire according to a low system reliability and 48 respondents according to a high system reliability. The outcome was that H2 was rejected ($F(1,89) = 2{,}299$; $p > 0{,}05$; $PE^2 = {,}025$). The mean ITU score of low system reliability ($M = 3{,}405$; $SD = 1{,}77$) was not significantly higher than the mean of high system reliability ($M = 3{,}859$; $SD = 1{,}58$), the level of system reliability has no effect on the mean of ITU (figure 8 and table 5).

Figure 7. Mean of ITU by level of technology reliability.

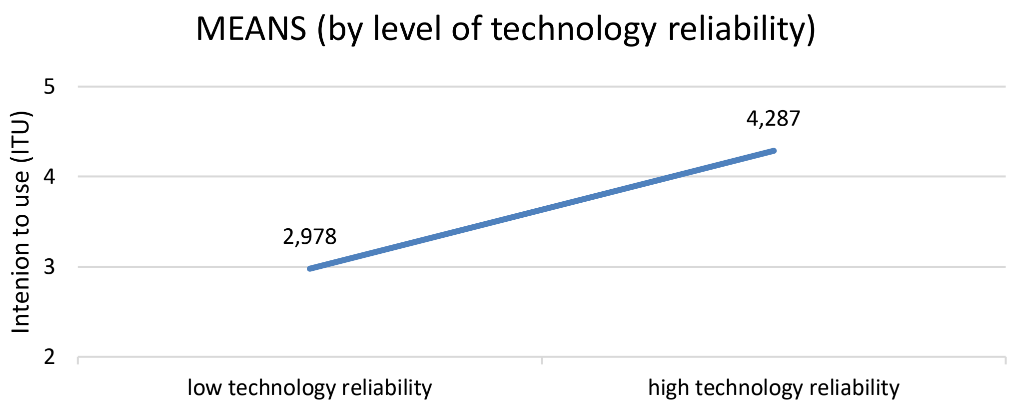

Figure 8. Mean of ITU by level of system reliability.

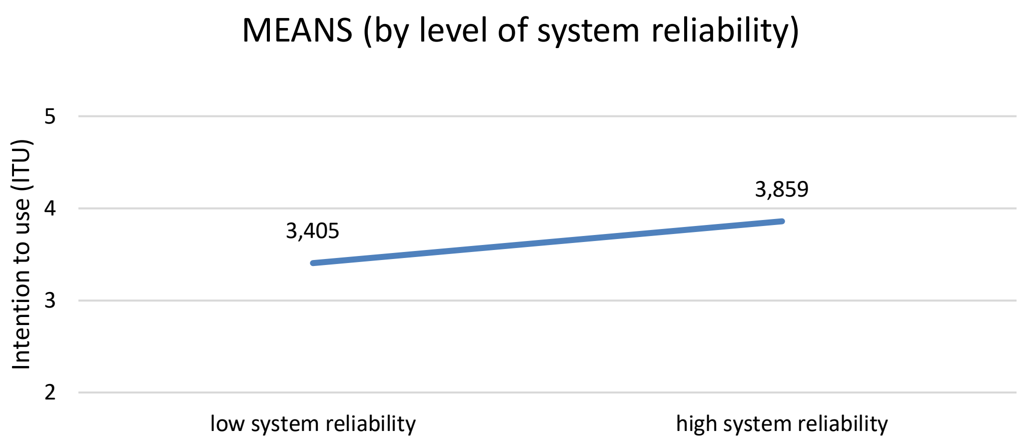

Table 5. Test of Between-Subjects Effect (dependent variable: ITU).

Source	SS	df	MS	F	p	PE^2
Technology reliability	39,775	1	39,775	19,095	,000	,177
System reliability	4,788	1	4,788	2,299	,133	,025
Technology reliability * System reliability	1,208	1	1,208	,580	,448	,006
Error	185,390	89	2,083			
Corrected Total	230,884	92				

a. R Squared = ,197 (Adusted R squared = ,170)

4.1.3 Effects covariates on ITU

The 2x2 subject design ANOVA was also used to control whether or not an interaction effect of technology reliability x system reliability had a significant effect on the ITU. The presence of interaction effects can be important because it tells how the two independent variables work together in their effect on ITU, which provides a better representation and understanding of the relationship between the types and levels of reliability on the ITU (Lavrakas, 2008). However, the results of this study showed no significant interaction effect by any means ($F(1,89) = ,580$; $p > 0,05$; $PE^2 = ,006$), the technology and system reliability did not work together in their effect on the ITU (table 5). To determine whether the control variables did have an effect on the ITU, an ANCOVA analysis was performed by the stages defined by Hair et al. (2018, p.384 and 402). Before actually looking at the effect of the covariates, the two other assumptions of ANCOVA (besides the ANOVA assumptions) had to be met. Firstly, the covariates and independent variables must be independent of each other. Secondly, the covariates must have a homogeneity of regression effect. While every covariate showed to be independent of both independent variables, the covariates tested the homogeneity of regression only regarding the system reliability. Conclusively, none of the covariates had a significant effect on the ITU and the answers on the hypothesises remained the same.

4.2 Results of qualitative study (focus group)

The examined focus group consisted of eight participants. The main characteristics from each participant of the focus group have been appointed below (table 6).

Respondent	Gender	Age	Educational background	Travel frequency	Daily travel time	Travel type
1	Female	28	Medicine	Daily	1hr.20min.	Car
2	Male	24	Communication science	2-4 times a week	50 min	Train
3	Female	26	Pedagogy	2 times a week	1hr.	Bus
4	Male	23	Business administration	3 times a week	2hrs.	Car
5	Male	25	Political science	2 times a week	3hrs.	Train/Bus
6	Male	27	Health science	Daily	40min.	Bus
7	Female	25	Geography	3 times a week	1hr.30min	Train/Bus
8	Male	26	Nursing	5 times a week	30min.	Car

Table 6. Basic characteristics of focus group participants.

4.2.1 Concept of reliability

The term 'reliability' is described by the participants as something that: they can rely on, it works, will do what it should do and can be trusted that it won't break or fail. What makes them consider or expecting a product to have a certain reliability depends on: the type of product, product age, brand, price, experience and usage history. The combination of these factors makes them having low reliability expectations about some products and high reliability expectations about other products: *"I don't expect a cheap product from AliExpress to last 2 years, but with an expensive Miele washing machine or new Mercedes yes I would expect it would certainly last for 5 years or more".* Regarding services, its consideration of reliability is largely the same, but the expectations are more based on the type of service, impact of the service, price and earlier experience: *"I expect hospitals to be super reliable when it comes to my or someone's life"* and *"A car dealer should provide better and more reliable service than a cheap garage yes [why?] well it's their own brand and also more expensive."* The importance of the level of reliability in a product or service depends strongly on the usage frequency, replaceability and level of safety according to the participants. Products and services that are used daily and are not quickly replaceable, like phones an laptops with important information, have a higher importance to be reliable. The ones which makes the difference between life and dead have the utmost importance of being extremely reliable: *"products that are of vital importance anyway such as a climbing rope or parachute or something, if that is not reliable then you do have a big problem."*

4.2.2 Reliability within transport

Participants determine the reliability of cars to the level they drive without problems, the engine starts and runs smoothly and brakes, lights, air-condition, sound systems, etc works. The less often the car has to go to the garage, the higher they perceive the reliability: *"The more a car has problems and the more often it has to go to the garage, the less reliable I find it."* Experiences with unreliability cars had mainly to do with engine and driving problems which meant the car stopped working or had to go a garage. On the question how participants have dealt with reliability issues, car reliability issues resulted in the following: hassle to go to the garage, insecurity about the issue, loss of trust, irritation, anger, added costs and having stress: *"My car stopped during vacation, yes then you do have stress of what to do and how to proceed. And the costs turned out to be quite high afterwards while the problem is still not completely solved."* But when low reliability is expected, for instance in the form of an old high milage car, it does not impact feelings or behaviour. Problems related to low reliability are easily accepted and they are often already taken into account. However, unexpected reliability issues influences opinions, feelings and behaviour in a negative way. If these negative feelings are too much to overcome, participants said to move to another car brand: *"My first car, a Citroën, that was a hassle. Yeah okay it wasn't the newest but it always had something. So I'm not going to buy a Citroën in the coming time no."* The reliability of public transport (train and bus) is determined on the service. Participants mentioned reliability as the level they can trust the time schedule and the transport does not depart too soon or arrives too late but precisely on the indicated time. Unreliability within transport had to do with malfunctions, transport arriving to late or departing to soon and being (too) full. Participants are much easier in dealing with unreliability in public transport than with cars. Regarding public transport, they only mentioned stress about arriving on time and looking at other travel options, as the rest is beyond their responsibility: "*Any delay is annoying because you don't know if you will be on time and stuff. But it's just waiting for the solution and yeah I mean for the rest it is not my problem."* While it is mentioned that delays in public transport are much more common than reliability issues with cars, it is also more accepted and therefore less problematic.

4.2.3 Technology reliability

The assessment of the driving technology reliability was determined on the level the vehicle drives (steers, gas, brakes) smoothly compared to known (human) driving and the amount of problems or failures in the driving technology occurs. The participants had the idea that if the driving technology does not work properly, there is a high chance of having an accident. Knowing an accident could happen due to failing driving technology made them immediately scared or anxious and highly restrict their intention to use AVs: *"I would be very anxious to step in a vehicle which has control over me and knowing it could fail. What if that happens on the highway, how big of a crash would that be?* None of the participants would use AVs if the technology reliability would be lower than that of conventional (human) driving. A driving technology that is more reliable than human driving is found to be the minimal requirement to use AVs: *"I think the whole Netherlands would say lower than that. I mean you cannot replace cars with something that is more dangerous, with cars being the already quite dangerous."* And *"It certainly needs to be lower than that of human driving. I know that people make mistakes, but with this (AVs) I could hardly accept that it makes a mistake, and who will be responsible for that?!"* The focus group revealed that road safety, acceptance of failing driving technologies and the question about responsibility and liability are the main factors that determines the acceptable level of technology reliability. To extract more knowledge, a comparison to other high automated transportation technologies like airplanes was made. The factors that showed to make the participants having a more positive opinion are: (1) the fact that are still people are still in charge who can take action when the technology fails, (2) the technologies have proven to be largely safe over several decades and (3) there is often no other option that comes close to price, travel time and convenience.

4.2.4 System reliability

The system reliability refers to amount of variation in travel times. The participants opinions about the system reliability is that a higher reliability is always better and wanted, but there is understanding that delays are inherent with complex technologies and intensive road use: *"I don't think there is any type of transport where you have no delays. You will always have traffic jams and roadworks or something like that, so yes I guess also with self-driving vehicles."* System unreliability or high variating travel times (delays) has two different effects depending on the expectation: (1) when expecting the (change of) delay(s) beforehand, the effect is that the trip is planned more broadly to make sure they will be at their destination on time and (2) when the delays are unexpected, the effect is that they get irritated, annoyed and become stressed whether they will be on time: *"It is the most annoying when you rushed to the train station, are there just in time and then hearing of some defect which means a delay of more than 1.5 hour."* How low system reliability would affect the intention to use AVs is dependable on the usage frequency and the substitutes AVs are used for. Participants that mainly used public transport tend to accept lower system reliability in travel time than people who uses cars as their main transportation. The fact current public transport systems takes almost always time to travel and/or wait before they can be used, makes the participants having no issues about waiting a while for AVs: *"Wouldn't be a problem to have to wait 15 minutes for that (AVs), when I take the train it also takes me at least 15 minutes to get to the station."* The acceptance for people that frequently uses their car is however much lower, as cars can be used at any time: *"I can take my car whenever I want. So if that will be replaced with something I have to wait for 10 minutes every time I need it, that would be a lot less chill."* Lost time that could be made up by bypassing traffic jams and decreasing travel time had however a positive effect.

4.2.5 Prove and communication of AVs reliability

The final discussion went about what is needed to help prove and convince AV reliability to the public. The results revealed that real world testing and experiences are the main practices to prove and convince the reliability of AVs. *"I know testing models and virtual test are helpful or necessary but that is not enough for me, It is important for me to know they work in the real world with like snow, thunder, road works etc."* Participants wants them to work in all circumstances like traffic, playing children, rain, snow etc, and real world testing is the way to convince them of those reliability facts. The discussion went further about how that should be facilitated. The conclusion of the participants is a stepwise approach: (1) try testing reliability with someone on board which can intervene, (2) starting with a special lane in an area where people know about the AV like a campus, (3) having an fixed route on an open road, (4) go from this fixed route to multiple routes, (5) size up to having an AV driving in a whole neighbourhood → city centre → whole city →etc. The most important what kept coming back is the need to become familiar with the self-driving vehicles. Participants mentioned that these familiarity and experiences can build a deep form of trust into the driving technology and overall system. *"I would like to experience the cars (AVs) in person, or at least here others that I know about it so that I trust that it is really reliable and not some publicity bullshit."* Besides this step-wise approach, communication of the reliability should be done via all sorts of media channels, some mentioned channels are: TV, radio, Instagram, YouTube and Netflix. It is said the explanation of how fully automated vehicles works, are tested, the advantages, disadvantages and what happens when failing are all useful information to know. Giving demos, free rides and sharing experiences of others is said to be helpful to further communicate and familiarize people with AVs. One thing that participants highlighted which can be difficult to overcome is the problem of crashes and injuries: "*Yes indeed, I have flown many times but if you here of a (deadly) plane crash its gets you thinking. And that can be a problem with AVs especially as if its new."*

5. General discussion

5.1 Theoretical implications

The academic literature has increasingly been studying the possibilities of AVs and its impact on the realm of transport, environment and human behaviour. It has been determined that many factors are effecting peoples intention to use AVs and researchers call for more studies involving other variables influencing the intention to use AVs (Golbabei et al., 2020; Keszey, 2020). In response, this is one of the few studies published so far that analyses the concept of AV reliability and explores how technology reliability & system reliability affect the intention to use AVs.

This study revealed that people demand a certain reliability level depending on the product / service expectations and importance. These expectations and importance of reliability depends on the combination of many factors: type of product / service, usage history, experience, brand, price, usage frequency, replaceability, repair costs and safety. With safety being the most important for the need of extreme reliability. The combined weighting of these factors differs when addressing a product or service. The public views the technology reliability as a product (such as cars), by which low technology reliability highly relates to having an accident. The acceptable level of technology reliability depends strongly on the frequency the self-driving technology fails and the factors of responsibility and liability when crashes occur. Is it not the first time these factors are mentioned, as they are a confirmation of earlier literature about barriers to the adoption of AVs (Fagnant and Kockelman, 2015; Bansal and Kockelman, 2017; Li et al, 2018). The public views the system reliability as a service (such as public transport), by which the level of system reliability is dependable on the usage frequency and the substitutes AVs are used for. Participants that mainly used public transport tend to accept lower system reliability than people who uses cars as their main transportation. System unreliability or having frequent delays has two different effects depending on the expectation: (1) when expecting the (change of) delay(s) beforehand, the effect is that the trip is planned more broadly to make sure they will be at their destination on time and (2) when the delays are unexpected, the effect is that they get irritated, annoyed and become stressed whether they will be on time. The combination of the driving technology and system around the AVs shows the complexity of what is needed to determine reliability levels that will be accepted by the public. When total reliability exceeds people's expectations, it does not affect their feelings and behaviour towards the type of transportation and brand. Reliability issues are easily accepted and they are often already taken into account. But when the reliability comes short to their expectations, it does affect their feelings through insecurity, loss of trust, irritation, anger and having stress. If these negative feelings are too much to overcome, people change their behaviour by being less intended to use the transport method and / or moving to another transport method when possible.

More so, the effect of technology reliability and system reliability on intention to use autonomous vehicles was explored. Empirical results of this study confirm the positive influence of technology reliability on intention to use (H1), confirming assertions in the literature (Hancock et al., 2011; Hengstler et al., 2016; Schoettle & Sivak, 2014; Fagnant & Kockelman, 2015). There is a significant effect of low and high technology reliability levels on the ITU. The study revealed that a driving technology which is more reliable than that of human driving is the minimum requirement for people to have the intention to use AVs. Knowing an accident could happen due to failing driving technology made people immediately scared and highly restrict their intention to use AVs. None of the participants would use AVs if the technology reliability would be lower than that of conventional (human) driving. The reason is that safety is mentioned as the most important for high reliability, and the level of technology reliability defines the possibility of having an accident. This in line with the results from earlier studies about AV acceptance and adoption (Raj, Kumar & Bansal, 2020). Furthermore, insecurity about road safety, acceptance of failing self-driving technology and who will be responsible and liable for crashes makes it also difficult for people to trust the new technology. And these trust issues due to low reliability levels have already found to restrict peoples usage intentions (Choi & Ji, 2015; Ward et al., 2017; Zhang et al., 2020). In addition to the first hypothesis, the results do not support the hypothesized positive influence of system reliability on intention to use AVs (H2). The system reliability does have positive effect on the ITU, but this effect is not significant by any means. In fact, it seemed that with a high technology reliability, the system reliability rather had a slightly negative effect on the ITU. This has likely to do with the expectations and experience people already have with low system reliability in current transportation. People are already used to longer travel times and delays due to traffic jams, malfunctions in public transport and time lost in traveling to bus / train stations. And when these delays are more expected, it does not affect their feelings and behaviour towards the type of transportation. So people tend to accept low system reliability more easily or it may have been already taken into account, which results in an insignificant effect.

Furthermore, the total explanatory effect of the model might be weak (R^2 = ,197), this is because human behaviour cannot be accurately predicted. An explanatory effect of around .20 is characterized as sufficient within human behaviour studies (Hair et al., 2018). And while none of the covariates did change the outcome of the hypothesises, there were some effects worth mentioning. Regarding the specific education level of HBO, the results did show a significant relation between the system reliability and ITU ($F(1,19) = 6,141$; $p < 0.05$; PE^2 = ,244). The mean ITU score of the low system reliability (M = 2,846; SD = 1,51) was significantly higher than the mean of high system reliability (M = 4,233; SD = 1,47). So it could be that, if the study contained more respondents with a HBO educational level, the study confirmed H2 by a significant effect of system reliability towards ITU. Regarding gender, the study shows that males tent to have a higher intention to use than females (M-males = 3,943; M-females = 3,425). This has mainly to do with the difference in ITU means regarding technology reliability, where males scored much higher (low-R = 3,155 vs high-R = 4,731) than females (low-R = 2,862 vs high-R = 3,988). This in line with earlier scientific research which determined that males are likely to have a greater intention to use or own AVs than females (Zmud et al, 2016; Kyriakidis et al, 2015; Robertson et al, 2017). Where the main reason, according to those studies, is that males are less worried about AVs and feel more confident to let them perform all driving functions. This study tents to confirm the conclusion that males are more confident on the driving technology if it has been proven to work reliable. Regarding age, the respondents in the age categories of 22-25 all the way to the age of 51-65 had grand means of ITU that were on the negative side of the scale (M = 3,323 >< 3,875 < 4). Only the respondents in the age categories of below 18 and above 65 had grand ITU means on the positive side of the scale (M-below 18 = 4,444 & M-65+ = 4,167 > 4). While these results should be interpreted with high cautiousness the groups were very small (only 1 respondent for age category 65+), the effect tends to be in line with the results from other academic literature. As some reported that younger people have a higher intention to use AVs (Robertson et al, 2017; Liu et al., 2019; Schoettle & Sivak, 2014) and others concluded that elderly had a higher intention to use (Nordhoff et al.,2018). This could be due to the fact that both youngsters and elderly could experience more freedom through AV usage, because they (more than the other age categories) can't carry out driving activities as they don't have access to a car or they don't have a driver's license (Rovira et al., 2019).

5.2 Managerial implications

While AVs are not yet available to the general public, this study provides managers with an overview on how technology and system reliability affect the ITU. Transferring the findings into the practical field, managers of AV developers & manufacturers should focus primarily on the technology reliability. By focusing on developing and manufacturing an AV that works as intended with sufficient technology reliability levels is very important in creating the intention to use AVs. An self-driving technology that is, perceived as, more reliable than human driving is the minimum requirement for people to use them. AV developers should therefore build an vehicle that truly achieves this requirement. It is however found that this could take decades to achieve and prove this type of reliability with testing alone (Kalra & Paddock, 2016). But again, prove of the vehicles being highly safe over several decades is necessary for a successful adoption of AVs. Therefore, a step-wise approach by which people can get familiar with the innovative fully automated technology and system is advised. It is revealed that this step-wise approach creates familiarity and experiences that are important in building a deep form of trust into the driving technology and overall system of AVs. This approach could have the following process: (1) test AVs with someone on board which can intervene, (2) then go full automated but start with a specific route in an area where people know about the AV, like an university or tech campus, (3) move to an fixed route on an open road, (4) go from one fixed route to multiple routes, (5) size up to having an AV driving in a whole neighbourhood, city centre, whole city, etc. The most important is people have the opportunity to become familiar with the innovative form of transport by which more and more people will intent to use the AVs over time. Participants mentioned that these familiarity and experiences can build a deep form of trust into the driving technology and overall system. This will help to succeed the forthcoming implementation and adoption of AVs.

Furthermore, it is worth mentioning that managers of AV developers & manufacturers should also focus on activities to improve the system reliability. While the study did not show a significant effect of system reliability towards the ITU, the commercialisation of electric vehicles by Tesla showed a reliable system is still important in order to have a successful adoption of a new type of transportation. And especially in the case of AVs, a transportation network of AVs will not work without a system around the AVs that enables the vehicles to be demanded and charged. It is therefore important for system developers to make sure the system is able to deliver the minimum requirements to keep the AVs usable. The advice is to be transparent about reliability issues in the system that can result in delays. When people are aware that delays could happen, the consequence is much less of a problem than when people do not expect any delays. When aware, people have the opportunity to plan around the delay and won't get as irritated, annoyed or stressed in comparison to when they are not aware. People that get irritated, annoyed or stressed will likely lose interest and trust into the autonomous vehicles which ultimately results in less intention to use AVs.

It is also advised that developers and implementers should invest in activities to prove and communicate the knowhow of AVs and their reliability. Using a wide spread of marketing activities through many (social) media channels about how the vehicles work, are tested, which benefits they possesses and what happens when failing to increase AV knowledge among the public. Other activities to familiarize people with AVs through demonstrations, free rides and user experience sharing could result in a more positive view towards AVs. One problem that needs to be tackled is that of negative news and experiences with crashes and injuries. This type of information can be a big barrier in the successful adoption of AVs. It is therefore highly recommended to carefully implement the vehicles, only when having tested rigorously and know the fail ratio is very low, to reduce the amount of negative news as much as possible.

6. Limitations and further research

The study gives more insight into AV reliability and its effects than the current literature so far, but certain limitations have to be taken into account which in turn suggest directions for further research. Although the scale used to measure the ITO was validated (Han et al., 2014), the first limitation relate to the conceptualisation and measurement scale of technology reliability and system reliability. There is no general agreement about what technology and system reliability in the case of AVs are nor the dimensions which constitute it. Therefore, the measurement scale in question was built especially for this study. While pre-tests, by means of an exploratory factor analysis in SPSS, were conducted to determine whether the questions had enough correlation without having cross-loadings. Both the pre-tests were done through an convenience sample, actual validation of the measurement items would be better if a more heterogeneous sample method was used.

The second limitation relates to the design and development of the scenarios. The scenarios in the surveys were given by means of a newspaper article. While it has been tried to give the respondent the most realistic feel of an actual newspaper article, through the design which included an image, title and name of the CEO from an real article of Krabbendam (2018), the manipulations about the different levels of reliability have been developed by the researcher himself. The usage of a complete description from a scientific article about technology and safety reliability would have taken this part to a higher level, which likely results in more valid and reliable measurements. However, an article that complied with the four manipulated scenarios has not be founded. The manipulation check did emphasize that the effectiveness of the scenarios in the experimental design had their limitations, as 16 of the 109 (14,68%) respondents failed the manipulation check. Especially the description of system reliability turned out to be somewhat unclear. This could be the reason that the hypothesis of system reliability was not confirmed by the study. More attention should be paid on the description of the system reliability for future research.

The third limitation is based on the acquisition of the data through the respondents. Therefore, the analysed results of data from the experiment and focus group should be treated with appropriate caution. Respondents of the experimental study were Dutch and mainly (ex) university students of the Radboud University and employees of the Wageningen University & Research. Respondents of the focus group were all between 23 and 28 years old. Which means the age of the respondents differs from the general age distribution and the educational level is much higher than the average of a country like the Netherlands. Therefore, the age and educational level might have been influencing the results. It would be risky to completely generalise the findings to consumers in the whole Netherlands.

The assumptions of the 2x2 subject design ANOVA were tested according to Hair et al. (2018, p. 393). The amount of 93 valid respondents exceeds the minimum of 80 (2x2x20) responses and each experimental sample had at least 20 valid responses. All the samples had insignificant Leven's test so the variance of the samples was equal. However, one sample (low technology reliability x low system reliability) had a significant score on the Shapiro Wilk test. The Q-plot showed a light tail with a right kurtosis of ,953. While this assumption could have had an influence on the final results, it should not have the biggest change due to the lightness of the tail. The main study contained one outlier due to a very low score on the ITU in comparison to all other scores in that sample (high technology reliability x high system reliability). But there was no reason to exclude the outlier from the study.

Based on the conclusions from this study, several recommendations can be made for further research. First of all, it is recommended to conduct further research into the system and technology reliability for future implementation of AVs. Although this research shows that the level of technology reliability are experienced to positively influence the intention to use AVs, this research mainly used high educated people from a developed country. It could be that people from less developed countries with lower education standards resolve in different results. It is therefore recommended to extent this research to a broader and more generic public. It is also recommended to conduct research into more specific levels of reliability. As mentioned in the literate review of this research, full reliability can't be reached and extensive development and testing is needed to establish a certain level of reliability. It may be valuable for AV developers to know with specific level of reliability is needed to get a certain percentage of people to use the AV. This will reduce time and cost of achieving a level of reliability that may not be necessary to successfully deploy their vehicle. Due to the nature of AVs being highly innovative, the late majority and laggards will naturally wait until the first movers and majority have tried the vehicles before they are willing to take the risks (Hardman et al., 2019). So the acceptance of the first movers and majority might be sufficient to persuade the lagging public of the (intended) use of the AVs.

7. Conclusion

This study aimed to dive deeper into the concept of AV reliability. AV reliability is therefore added to the theoretical framework regarding peoples intention to use AVs in order to help succeeding the future adoption of autonomous vehicles. Studies have determiend many variables that influences the intention to use AVs, but the effect of reliability is something that was missing in the current literature (Keszey, 2020; Golbabei et al., 2020). Because of the high complexity of AVs, its reliability was divided into the technology reliability and the system reliability. This resulted in the main research question of this study; what is the effect of technology reliability and system reliability on the intention to use autonomous vehicles? Based on this research question, two hypothesises were developed: (H1) technology reliability has a positive effect on the intention to use AVs; and (H2) system reliability has a positive effect on the intention to use AVs. An experimental design has been used to seek an answer to the two hypothesises. The results show that technology reliability does have a significant positive effect on the ITU. An increase in the level of technology reliability also increases the ITU. A self-driving technology that is more reliable than human driving is revealed as a minimum requirement for people wanting to use AVs. The results show that system reliability does not affect the ITU. While there was a slight positive measured effect on the ITU, this effect was weak and therefore not significant by any means. People are already familiar with system unreliability in public transportation which makes having delays less problematic. While the study determined that only the technology reliability has a significant impact the intention to use AVs, there is more needed to help succeeding the adoption of AVs. The desired level of AV reliability to accomplish public acceptance is a complex outcome of multiple factors regarding product / service expectations, importance, safety, usage frequency, reliability of substitutes, etc. AV developers should therefore not only focus on the level of technology reliability, but on the combined outcome of all different factors influencing the level of reliability. Conclusively, an acceptable level of AV reliability is needed for a succesfull adoption and implementation of autonomous vehicles.

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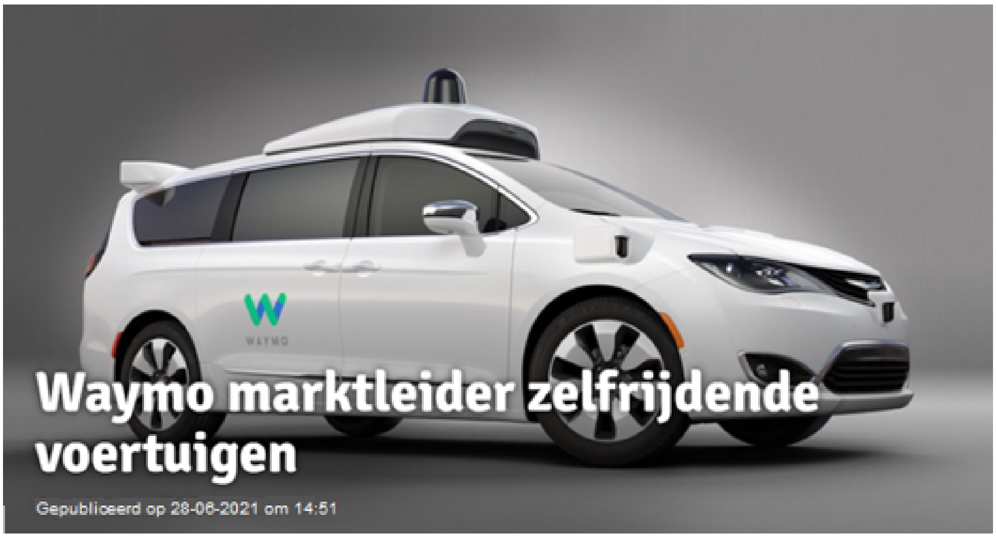
Appendix

Appendix 1. Newspaper articles

Article 1 – high technology reliability vs high system reliability



WAYMO (voorheen het zelfrijdende auto project van Google) is de marktleider van zelfrijdende voertuigen. Het zelfrijdende voertuig is volledig geautomatiseerd dus het is onmogelijk voor mensen om het voertuig handmatig te besturen. Het voertuig is ontworpen om het menselijk rijden volledig te kunnen vervangen. Voormalig CEO van WAYMO, John Krafcik, vertelde het volgende over de rijtechnologie en het systeem van hun zelfrijdende voertuigen.

"De rijtechnologie maakt gebruik van LIDAR, SONAR & camera's en stelt daarmee het voertuig in staat te rijden zonder dat input van een mens nodig is. De rijtechnologie is getest op meer dan 100 miljoen kilometer gedurende een periode van 14 jaar. In totaal zijn de zelfrijdende voertuigen betrokken bij 12 kleine ongevallen, zonder ook maar één met dodelijke afloop. Ter vergelijking: per 100 miljoen kilometer veroorzaakt menselijk rijden meer dan 50 ongevallen, waarvan er minstens één met dodelijke afloop is. De reden van dit veilige rijden is dat de rijtechnologie (in tegenstelling tot mensen) nooit problemen heeft met het detecteren van verkeerslichten, verkeersborden en weggebruikers, zelfs niet bij hevige regen en/of sneeuwval. Daarnaast kan ik met trots melden dat de prestaties van de geteste voertuigen over hun gebruiksperiode niet achteruit zijn gegaan."

"Het systeem bestaat uit een applicatie, laadstations, gedetailleerde wegenkaarten en back-upsystemen. Het systeem maakt het mogelijk een voertuig met een app op te vragen, het voertuig naar uw locatie te sturen en vervolgens via de snelste route naar uw bestemming te brengen. Het systeem is vanaf 2016 tot heden onder verschillende omstandigheden getest. Uit de tests blijkt dat de voertuigen probleemloos alle opgevraagde locaties herkennen, wat betekent dat ze binnen 2 minuten van de aangegeven tijd arriveren. Verder tonen de tests aan dat het systeem de gebruikers altijd een volledig opgeladen voertuig geeft en systematisch de snelste route selecteert. Dit resulteert in constante reistijden waardoor de aangegeven aankomsttijden op de eindbestemming altijd zeer nauwkeurig zijn."

Article 2 – high technology reliability vs low system reliability

WAYMO (voorheen het zelfrijdende auto project van Google) is de marktleider van zelfrijdende voertuigen. Het zelfrijdende voertuig is volledig geautomatiseerd dus het is onmogelijk voor mensen om het voertuig handmatig te besturen. Het voertuig is ontworpen om het menselijk rijden volledig te kunnen vervangen. Oud CEO van WAYMO, John Krafcik, vertelde het volgende over de rijtechnologie en het systeem van hun zelfrijdende voertuigen.

“De rijtechnologie maakt gebruik van LIDAR, SONAR & camera’s en stelt daarmee het voertuig in staat te rijden zonder dat input van een mens nodig is. De rijtechnologie is getest op meer dan 100 miljoen kilometer gedurende een periode van 14 jaar. In totaal waren de zelfrijdende voertuigen betrokken bij 80 ongevallen, waarbij 3 met een dodelijke afloop. Ter vergelijking: per 100 miljoen kilometer veroorzaakt menselijk rijden ongeveer 50 ongevallen, waarvan maar één met dodelijke afloop. De ongevallen waren vooral het gevolg van problemen bij het detecteren van verkeerslichten, verkeersborden en weggebruikers bij hevige regen en/of sneeuwval. De detectieproblemen vonden met name plaats aan het einde van de gebruiksperiode omdat de prestaties van de rijtechnologie langzaam achteruitgaan.”

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Article 3 – low technology reliability vs high system reliability

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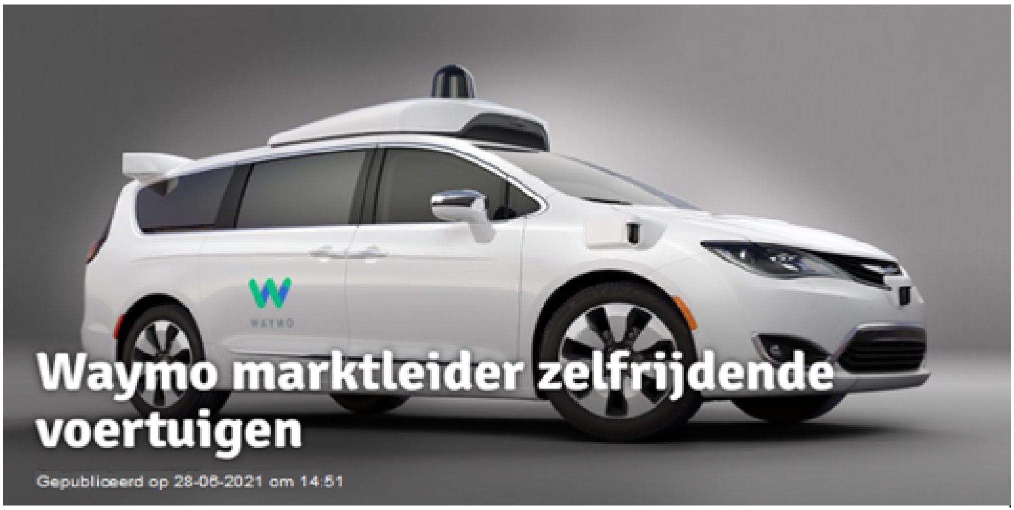
Article 4 – low technology reliability vs low system reliability



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Appendix 2. Questionnaire (Dutch)

Zelfrijdende voertuigen

Fijn dat u wilt deelnemen aan mijn onderzoek!

Mijn naam is Mathijs Korbee, ik ben een student aan de masterspecialisatie Innovatie & Ondernemerschap aan de Radboud Universiteit Nijmegen. Het onderzoek gaat over zelfrijdende voertuigen en bestaat uit twee delen. De gegevens worden volledig anoniem en vertrouwelijk verwerkt en de resultaten worden alleen gebruikt in het kader van mijn Master thesis. U bent te allen tijde vrij om de survey af te breken en neem bij vragen gerust contact met mij op (0645644611 / m.korbee@student.ru.nl).

Het eerste deel van dit onderzoek bevat een krantenartikel over zelfrijdende voertuigen van WAYMO, door middel van stellingen wordt uw mening / standpunt over deze voertuigen getoetst. Het tweede deel bestaat uit een zevental algemene vragen. De totale vragenlijst bevat 18 stellingen / vragen, het invullen duurt ongeveer 5 minuten.

Alvast hartelijk dank voor uw deelname!

Deel 1 - lees het onderstaande krantenartikel

One of the four version of the newspaper articles → Appendix 1

Q1-4

De volgende 4 stellingen gaan over de betrouwbaarheid van de rijtechnologie (de kans dat de rijtechnologie niet goed werkt of uitvalt)

Geef met behulp van het krantenartikel aan in hoeverre u het eens bent met de stellingen:

	Sterk mee oneens	Oneens	Beetje mee oneens	Neutraal	Beetje mee eens	Eens	Sterk mee eens
Door de rijtechnologie wordt de kans op fatale (ongelukken) vergroot.	○	○	○	○	○	○	○
De rijprestaties van de voertuigen blijven over de gehele gebruiksperiode gelijk.	○	○	○	○	○	○	○
De voertuigen detecteren de verkeerstekens en weggebruikers probleemloos in alle weersomstandigheden.	○	○	○	○	○	○	○
De zelfrijdende voertuigen maken het rijden veiliger dan het traditionele (door mensen bestuurde) rijden.	○	○	○	○	○	○	○

Q5-8

De volgende 4 stellingen gaan over de systeem betrouwbaarheid (de kans dat het systeem rond het voertuig niet goed werkt of uitvalt met vertragingen als gevolg)

Geef met behulp van het krantenartikel aan in hoeverre u het eens bent met de stellingen:

	Sterk mee oneens	Oneens	Beetje mee oneens	Neutraal	Beetje mee eens	Eens	Sterk mee eens
De daadwerkelijke vertrektijd vanaf locatie is altijd nauwkeurig te bepalen.	○	○	○	○	○	○	○
De echte reistijd kan afwijken van de opgegeven reistijd door toedoen van het systeem.	○	○	○	○	○	○	○
De daadwerkelijke aankomsttijd op de eindbestemming is altijd nauwkeurig te bepalen.	○	○	○	○	○	○	○
Door inconsistentie van het systeem worden vertragingen in de hand gewerkt.	○	○	○	○	○	○	○

Q9-11

Geef aan hoe u denkt over de volgende 3 stellingen met betrekking tot het gebruik van het zelfrijdende voertuig.

	Sterk mee oneens	Oneens	Beetje mee oneens	Neutraal	Beetje mee eens	Eens	Sterk mee eens
Ervan uitgaande dat ik toegang heb tot de zelfrijdende voertuigen, ben ik bereid deze te gebruiken.	○	○	○	○	○	○	○
Ik ben van plan het zelfrijdende voertuig te gaan gebruiken.	○	○	○	○	○	○	○
Ik zal mijn best doen om van de zelfrijdende voertuigen gebruik te maken.	○	○	○	○	○	○	○

Deel 2 - Algemene vragen

Q12 - Wat is uw geslacht?

○ Man

○ Vrouw

Q13 - Wat is uw leeftijd?

- ○ 18 t/m 21 jaar
- ○ 22 t/m 25 jaar
- ○ 26 t/m 30 jaar
- ○ 31 t/m 40 jaar
- ○ 41 t/m 50 jaar
- ○ 51 t/m 65 jaar
- ○ ouder dan 65 jaar

Q14 - Wat is uw hoogst genoteerde opleiding?

- ○ Basisonderwijs
- ○ Voortgezet onderwijs
- ○ MBO
- ○ HBO
- ○ WO / Universiteit

Q15 - Wat is uw huidige beroep / functie?

- ○ Student
- ○ Loondienst
- ○ Zelfstandige
- ○ Werkloos
- ○ Anders

Q16 - Hoe lang bent u in het bezit van een rijbewijs?

- ○ Niet
- ○ 1 jaar
- ○ 2 t/m 5 jaar
- ○ 6 t/m 10 jaar
- ○ Langer dan 10 jaar

Q17 - Hoe vaak maakt u gemiddeld gezien gebruik van een auto?

- Dagelijks (5-7 dagen per week)
- Een paar dagen in de week (2-4 dagen per week)
- Eén keer per week
- Eén tot paar keer per maand
- Overig (minder frequent)

Q18 - Hoe vaak maakt u gemiddeld gezien gebruik van het openbaar vervoer?

- Dagelijks (5-7 dagen per week)
- Een paar dagen in de week (2-4 dagen per week)
- Eén keer per week
- Eén tot paar keer per maand
- Overig (minder frequent)

Als u benieuwd bent naar de resultaten van deze studie, stuur dan een email naar: m.korbee@student.ru.nl

Druk nu op het pijltje om de survey officieel af te sluiten, ik dank u hartelijk voor uw medewerking

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Appendix 3. PowerPoint focus group (Dutch)


BETROUWBAARHEID VERVOERSMIDDELEN
→Openbaar vervoer
→Auto
• Hoe bepalen jullie of een vervoersmiddel betrouwbaar is?
• Wat zijn jullie ervaringen met onbetrouwbare vervoersmiddelen?
• Hoe gingen jullie om met deze onbetrouwbaarheid?
• Hoe heeft dit jullie gedrag met betrekking tot het gebruik van dat vervoersmiddel beïnvloed?


TECHNOLOGISCHE BETROUWBAARHEID
Zelfrijdende auto's bezitten naast de componenten van hedendaagse vervoersmiddelen (chassis, motor, banden etc.) een nieuwe rijtechnologie. De rijtechnologie stelt de auto's in staat om te rijden zonder dat input van een mens nodig is d.m.v. lasers, sensoren en navigatie.
De rijtechnologie heeft 3 hoofdfuncties:
1. Sturen
2. Remmen
3. Gas geven
= de betrouwbaarheid van de rijtechnologie


TECHNOLOGISCHE BETROUWBAARHEID
• Aan de hand van welke criteria zouden jullie de betrouwbaarheid van de rijtechnologie bepalen?
• Hoe belangrijk is een goed functionerende rijtechnologie?
• Wat zou er volgens jullie kunnen gebeuren als deze technologie gebreken vertoond?
• Hoe zouden deze gebreken jullie gebruiksintentie van zelfrijdende voertuigen beïnvloeden?


TECHNOLOGISCHE BETROUWBAARHEID
Informatie: 90% of alle ongelukken wordt veroorzaakt door menselijke rijden. Per 100 miljoen gereden kilometers veroorzaakt menselijk rijden meer dan 50 ongevallen, waarvan er minstens 1 dodelijk is.
• Stelling 1: Ik accepteer dit ook van zelfrijdende voertuigen. Leg uit?
• Vraag: Wat en waarom zou dan een acceptabel niveau zijn?
• Stelling 2: Ik stap zonder twijfels over de betrouwbaarheid van vliegsystemen in een vliegtuig. Leg uit?
• Vraag: Wat maakt dat jullie hier anders nadenken over de betrouwbaarheid van deze autonome technologie?

SYSTEEM BETROUWBAARHEID

Zelfrijdende auto's moeten net zoals openbare vervoersmiddelen over een systeem beschikken die het gebruik van het voertuig faciliteert. Dit systeem bevat o.a. de volgende functies:

1. App om het voertuig aan te vragen
2. Oplaad stations
3. Minimaal aantal rijdende voertuigen

De betrouwbaarheid van het systeem bepaalt met name de reistijd van de zelfrijdende voertuigen en de hoeveelheid vertraging die optreedt.

SYSTEEM BETROUWBAARHEID

- Wat is het belang van een betrouwbare reistijd?

- Wanneer accepteren jullie variatie in de reistijd, en waarom?

- Auto / Openbaar vervoer

- Wanneer zijn vertragingen het grootste probleem?

- Auto / Openbaar vervoer

- Welke effect heeft vertraging in het reizen op jullie en het gebruik van het vervoersmiddel?

SYSTEEM BETROUWBAARHEID

Informatie: Ongeacht het type vervoersmiddel, vertraging door middel van storingen, files en menselijke fouten komen dagelijks voor.

- **Stelling 1:** Ik kies voor een zelfrijdende auto als de reistijd hetzelfde is als een normale auto. Leg uit?
- **Vraag 1:** Hoe zal je gebruiksintentie veranderen als:

- zelfrijdende auto's files zullen omzeilen?
- Het gebruik van zelfrijdende auto's files en uitstoot drastisch omlaag zou brengen

- **Stelling 2:** Ik kies voor een zelfrijdende auto als de reistijd hetzelfde is als een bus/trein. Leg uit?

VASTSTELLEN EN COMMUNICEREN VAN BETROUWBAARHEID

- Hoe staan jullie tegenover het testen van de zelfrijdende voertuigen op straat, en waarom?
- Op welke manier zou de tests in de praktijk gefaciliteerd kunnen worden?
- Wat zou er moeten gebeuren als de testvoertuigen betrouwbaarheidsproblemen hebben?
- Hoe moeten fabrikanten de betrouwbaarheid naar het publiek communiceren?
- Wat kunnen organisaties nog meer doen om het publiek te overtuigen van de betrouwbaarheid?


VRAGEN EN
OPMERKINGEN