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Development and transport implications of automated vehicles in the Netherlands: scenarios for 2030 and 2050

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Automated driving technology is emerging. Yet, little is known in the literature about when automated vehicles will reach the market, how penetration rates will evolve and to what extent this new transport technology will affect transport demand and planning. This study uses scenario analysis to identify plausible future development paths of automated vehicles in the Netherlands and to estimate potential implications for traffic, travel behaviour and transport planning on a time horizon up to 2030 and 2050. The scenario analysis was performed through a series of three workshops engaging a group of diverse experts. Sixteen key factors and five driving forces behind them were identified as critical in determining future development of automated vehicles in the Netherlands. Four scenarios were constructed assuming combinations of high or low technological development and restrictive or supportive policies for automated vehicles (AV …in standby, AV …in bloom, AV …in demand, AV …in doubt). According to the scenarios, fully automated vehicles are expected to be commercially available between 2025 and 2045, and to penetrate the market rapidly after their introduction. Penetration rates are expected to vary among different scenarios between 1% and 11% (mainly conditionally automated vehicles) in 2030 and between 7% and 61% (mainly fully automated vehicles) in 2050. Complexity of the urban environment and unexpected incidents may influence development path of automated vehicles. Certain implications on mobility are expected in all scenarios, although there is great variation in the impacts among the scenarios. Measures to curb growth of travel and subsequent externalities are expected in three out of the four scenarios.

Keywords: *Automated vehicles, development, implications, scenarios, The Netherlands.*

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1. Introduction

The introduction to the market, the development and the implications of automated driving are among the main uncertainties of the future transport system. Automated vehicles could have significant impacts on urban and transport systems (Correia & van Arem, 2016; Fagnant & Kockelman, 2015; Ioannou, 1997; Milakis, van Arem and van Wee, 2015). The design of robust long-term transport policies and investments needs to take into account uncertainties associated with automated vehicles. However, little is known in the literature about when automated vehicles will reach the market, how penetration rates will evolve and to what extent this new transport technology will affect transport demand and planning. There are multiple approaches to fill parts of this knowledge gap. The deployment of automated vehicles has been mainly explored in the US context based on questionnaire surveys of experts (Underwood, 2014) and public opinion (see Bansal and Kockelman, 2016), analysis of deployment of comparative vehicle technologies (Litman, 2014) and scenario analysis (see Townsend, 2014, Zmud *et al.*, 2015). The transport impacts of automated vehicles have been explored based on multiple approaches ranging from traffic simulation (see van Arem *et al.*, 2006), field experiments and analytical methods (see Rajamani and Shladover, 2001) to system dynamics (see Gruel and Stanford, 2015), agent-based simulation methods (see Fagnant and Kockelman, 2014) and activity-based travel demand models (see Childress et al., 2015).

This study contributes to the growing literature focusing on the questions of development and transport implications of automated vehicles from a qualitative methodological perspective based on experts' opinions in the European context. We apply the long-established intuitive logics scenario development method (see Bradfield *et al.*, 2005, Amer *et al.*, 2013, Wright *et al.*, 2013) to identify plausible future development paths of automated vehicles in the Netherlands and to estimate potential implications for traffic, travel behaviour and transport planning on a time horizon up to 2030 and 2050. We have chosen 2030 and 2050 because our study is linked to the wider foresight study about mobility in the Netherlands (i.e. Prosperity and Environment - WLO, see Snellen *et al.*, 2015) and that study focuses on these future years. Our research questions are the following:

- What are the possible developments for automated vehicles and which factors will determine these developments on a time horizon up to 2030 and 2050 in the Netherlands? What stages can be distinguished in this development?
- What are the implications for road capacity? Does this differ between urban roads, regional roads and motorways?
- What are the implications for users (value of time) and consequently for travel behaviour?
- To what extent might automated vehicles affect transport planning?

The rest of this paper is structured as follows. Section 2 presents the background literature about the development and potential implications of automated vehicles on traffic, travel behaviour and transport infrastructures. In section 3, we describe our methodology for the construction of the scenarios and in section 4 we present four scenarios about the development and possible effects of automated vehicles in the Netherlands. We close this paper with the conclusions in section 5.

2. Development and implications of automated vehicles in the literature

2.1 Development of automated vehicles

The development of automated vehicles technology takes place along two dimensions. First, the driving automation dimension, which varies from manual to automated and describes the extent to which the human driver monitors the driving environment and executes aspects of the dynamic driving task. Second, the connectivity dimension, which varies from autonomous to cooperative and describes the extent to which vehicles can communicate and exchange information with other vehicles (V2V) or with the infrastructure (V2I). For the driving automation dimension, two main taxonomies that classify the levels of vehicle automation have been identified (National Highway Traffic Safety Administration (NHTSA), 2013, SAE International, 2014). In both taxonomies the first three levels (levels 0 to 2) assume that a human driver will control the dynamic driving tasks and/or monitor the driving environment with the help of driver assistance systems. The remaining levels (3 and 4, NHTSA and 3 to 5, SAE International) assume that an automated driving system takes control of all dynamic tasks of driving and monitors the driving environment. In conditional automation, (level 3 in both taxonomies) the driver is expected to be available for occasional control of the vehicle, while in full automation (level 4, NHTSA and levels 4 and 5, SAE International) s/he is not. SAE International splits the level of full automation based on whether the vehicle will be able to drive itself in specific (e.g. high speed cruising or closed-campus operation, level 4) or in all driving modes (level 5). Full automation comprises both occupied and unoccupied vehicles. In our scenario study, we use the National Highway Traffic Safety Administration (NHTSA) taxonomy for vehicle automation because SAE International taxonomy would add unnecessary complexity about different specifications of full automation. We refer to level 3 and level 4 as ‘conditional’ and ‘full’ automation respectively. The level of connectivity between vehicles is also critical, because it may bring additional efficiency benefits (e.g. increase road capacity; see Shladover et al., 2012).

Several studies have attempted to explore market introduction and evolution of penetration rates for automated vehicles. According to a survey held during the Automated Vehicles Symposium 2014, experts expect conditionally and fully automated vehicles to reach the market in 2019 and 2030 respectively (median values) (Underwood, 2014). The range of estimation for market introduction varied between 2018 and 2020 for conditional automation on freeways and between 2027 and 2035 for full automation. Litman (2014) estimated the penetration rate of fully automated vehicles assuming that they will reach the market in 2020. He based his estimations on the deployment of previous vehicle technologies like air bags, automatic transmission, navigation systems, GPS services, hybrid vehicles and on assumptions about the purchase price of these vehicles. He concluded that, in the United States, it may take ten to thirty years from the time of launch before the automated vehicle dominates the car sales market and another ten to twenty years before the majority of travel is done using automated vehicles. Kyriakidis et al. (2015) conducted a public opinion internet-based questionnaire survey with 5000 respondents from 105 countries. Sixty-nine percent of the respondents expected fully automated vehicles to reach 50% penetration rate by 2050.

Considering scenario analysis methods, a recent study in the US context identified two plausible deployment paths for automated vehicles: the revolutionary and the evolutionary (Zmud et al., 2015). In the revolutionary path the private sector (original equipment manufacturers - OEMs, suppliers, technology firms) invests heavily in automated driving technology, while US governmental policy promotes this emerging transport technology (e.g. through tax credits). Fully automated vehicles reach the market as early as 2020, while by 2025 a significant number of those vehicles are present on the roads. In the evolutionary scenario, OEMs and suppliers follow an incremental approach in developing vehicle automation technology. Policy, regulatory as well as technical problems delay deployment of fully automated vehicles. Thus, fully automated vehicles are introduced to the market around 2040, while ten years later (2050) a significant number of those vehicles circulate on the roads. Another scenario study identified four plausible deployment paths of vehicle automation in the US context (growth, collapse, constraint and transformation) reflecting different technological development, market and regulatory conditions in the future (Townsend, 2014). In two scenarios (growth and collapse), fully automated vehicles are introduced to the market around 2020, while by 2030 a significant share of the vehicles’ fleet consists of fully automated vehicles (between 25% and 35%). The other two scenarios (constraint and transformation) envision radically different transport systems, where (private) automated vehicles are not key components. Finally, a recent report of the Institute for Transport Policy Analysis in the Netherlands (Tillema *et al.*, 2015) identified four scenarios for development of automated vehicles. The scenarios were built around variations of the level of vehicle automation technology and the level of vehicle and ride sharing (i.e. mobility as a service: any time any place, fully automated private luxury, letting go on highways, and multimodal and shared automation). These scenarios do not have a specific time horizon, but they represent a final stage of the transport system. Thus, they do not explicitly refer neither to market introduction of various levels of vehicle automation, nor to possible evolution of penetration rates of automated vehicles.

In conclusion, the actual speed of development of automated vehicles and the precise nature of the transition path (mix of vehicles with different levels of automation and degree of cooperation) remains unclear. Several studies have explored deployment of automated vehicles using questionnaire surveys to experts, online surveys to general population, analysis of deployment of comparative vehicle technologies and scenario analysis. Most of the studies refer to the US context. In the Dutch context, a scenario study described possible end states but not a specific time horizon for deployment and implications of automated vehicles.

2.2 *Impacts of automated vehicles on road capacity, travel behaviour and transport infrastructures*

Automated vehicles could enhance road capacity by optimizing driving behaviour with respect to time gaps, speed and lane changes (see Hoogendoorn et al., 2014). The magnitude of this impact is related to the level of automation and cooperation between vehicles. Thus far, literature focuses on the automation of longitudinal driving, with the help of adaptive cruise control (ACC) and cooperative adaptive cruise control (CACC). Almost all studies are based on micro-simulations, sometimes in combination with a field test. These studies indicate that ACC can either have a small negative or a small positive effect on capacity (-5% to +10%). This is related to factors such as penetration rate, on/off switch of the system, the type of actuator (see Minderhoud, 1999) as well as the time gap used. If the time gap is greater than the time gap maintained by motorists without ACC, then capacity decreases (e.g. van Arem and Smits, 1997; VanderWerf et al., 2002; VanderWerf et al., 2004). For CACC, most studies report a quadratic increase in capacity as the penetration rate increases, with a theoretical maximum increase of 100% (doubling). The extent of capacity increase depends on the time gaps used and the presence of bottlenecks. Most studies indicate that the increase in capacity is high (>10%) only if the penetration rate is higher than 40% (e.g. Arnaout and Bowling, 2011; Calvert et al., 2011; Shladover et al., 2012).

The effect of automated vehicles on travel behaviour has not yet been thoroughly examined in the literature. Automated vehicles are expected to increase travel comfort, travel time reliability and travel enrichment (i.e. multitasking while traveling) therefore leading to lower values of time (Milakis et al., 2016). According to Cyganski et al. (2015) benefits such as window gazing, relaxing and working while traveling with an automated vehicle were positively assessed by 250 subjects of their online survey in Germany. A decrease in values of time could trigger changes in travel behaviour both with respect to mode choice and travel distances, and maybe also trip frequency and time of day (because congestion levels can change and additional travel time due to congestion can be valued differently). However, to the best of our knowledge, no studies have systematically explored the impacts of automated vehicles on values of time yet. In the Dutch context, KIM (2013) has shown that the value of time for commuter and business traffic has decreased to a larger extent than might have been expected based on income changes over the past two decades. A possible hypothesis is that this is because of the introduction of mobile phones, so that time spent in the car can be utilised more efficiently. While this phenomenon of travel time enrichment (Gunn, 2001) offers certain clues about the potential effect of automated vehicles on value of time, the question remains: how much further can travel time enrichment be increased as a result of the introduction of automated vehicles? Malokin et al. (2015) showed that the ability of multitasking in automated vehicles could increase driving alone and shared ride commute shares by 1% each. Gucwa (2014) applied several scenarios of potential changes in the value of time because of introduction of automated vehicles in San Francisco. He found an increase in vehicle kilometres travelled (VKT) between 4% and 8% for different scenarios. Moreover, two simulation studies reported increased VKT rates for automated (vehicle and ride) sharing schemes compared to privately owned conventional vehicles (Fagnant and Kockelman, 2014; International Transport Forum, 2015).

The introduction of automated vehicles is expected to reduce the need for conventional road infrastructure investments (extra-wide lanes, wide shoulders, guardrails, rumble strips, stop signs) (Silberg et al., 2012). Moreover, possible improvements in road capacity (subject among other factors to strategies for entering/exiting automated driving lanes, crossings between manual and automated driving, separation policies for manual and automated vehicles, see Minderhoud, 1999) could reduce the requirements for road network expansion in the future. Estimations about the magnitude of this reduction vary from substantial (Silberg et al., 2012) to only marginal because of the possibility of induced travel demand (Wagner et al., 2014; Litman, 2014; Fagnant and Kockelman, 2015). Increases in road capacity may also create the opportunity for development of bicycle and pedestrian infrastructures (i.e. bicycle lanes or wider sidewalks) (Milakis et al., 2016). Although, needs for conventional road infrastructure could be lower in the future, additional important investments may be necessary for physical and digital infrastructures for automated vehicles. According to Silberg et al. (2012) the transition to automated vehicles-based infrastructure might be proven highly costly especially when it comes to connected vehicles or communication between vehicles and infrastructure. Finally, automated vehicles could challenge the role of public transport in the future transport system and therefore influence investment decisions on public transport infrastructures (Litman, 2014; Anderson et al., 2014). Two of the main reasons are the enhanced travel comfort of automated vehicles along with the flexibility and reduced operation costs of automated shared mobility services.

In conclusion, research has mainly focused on impacts of automated vehicles on traffic flow efficiency and subsequently on road capacity. Capacity impacts of ACC are expected to be small and could be either positive or negative. CACC could have a positive impact of more than 10% on road capacity for a penetration rate higher than 40%. Studies on travel behaviour are relatively sparse and more recent. These studies show that (shared) automated vehicles could increase total VKT. Implications of automated vehicles for transport infrastructures are mainly discussed in professional rather than in scholarly literature. The needs for conventional road infrastructure might be lower in the future, but additional investments for physical and digital infrastructures for automated vehicles could be necessary as well.

3. Methods

The aim of this study is to identify plausible future development paths of automated vehicles in the Netherlands and to estimate potential subsequent implications for traffic, travel behaviour and transport planning on a time horizon up to 2030 and 2050. Given the uncertainty and the long-term character of this problem, a scenario analysis was applied.

Scenario analysis is "the process of evaluation possible future events through the consideration of alternative plausible, though, not equally likely, states of the world" (Mahmoud et al., 2009: 798). It has been used both in private and public sectors to develop strategic plans (e.g. large capital investments, plans for regional development or transport investments) that could accommodate uncertainty of the future (Maack, 2001; Peterson et al., 2003; Bradfield et al., 2005; Bezold, 2010). According to Stead and Banister (2003) scenario analysis can tell us what might happen in the future and help us acquire insights on how to avoid adverse outcomes. Scenarios have the advantage over forecasts in that they are more flexible, creative and not necessarily probabilistic outlines of plausible futures. Thus, they could assist long-term planning to broaden perspectives and identify key dynamics (Mahmoud et al., 2009).

In this study, we followed the intuitive logics approach, which has been the main methodological paradigm for scenario building during the last decades (see Bradfield *et al.*, 2005, Amer *et al.*, 2013, Wright *et al.*, 2013). Intuitive logics approach identifies alternative plausible states of the world and describes the hypothetical sequence of events (causal processes and decision points) that can lead to them. It does not involve use of any mathematical algorithms, but it is based on the knowledge, commitment, credibility and communication skills of the scenario team members (Amer et al., 2013). According to Maack (2001) and Townsend (2014) scenarios should be plausible, distinctive (i.e. to utilize different combinations of key forces), consistent (i.e. to have a strong internal logic), relevant (i.e. to offer insights to the focal issue), creative (i.e. to reflect innovative thinking), and challenging (i.e. to challenge conventional thinking and assumptions).

Whilst methodologies for scenarios' construction show great variation (Martelli, 2001; Bishop et al., 2007), there is a basic common underlying structure (see Schoemaker, 1995; Schwartz, 1996; Bood and Postma, 1997; Amer et al., 2013). In our study, the scenario development process involved five sequential steps (see Figure 1): (a) identification of key factors and driving forces of development of automated vehicles, (b) assessment of impact and uncertainty of driving forces, (c) construction of the scenario matrix, (d) estimation of penetration rates and potential implications of automated vehicles in each scenario, and (e) review of the scenarios and assessment of the overall impact of each scenario.

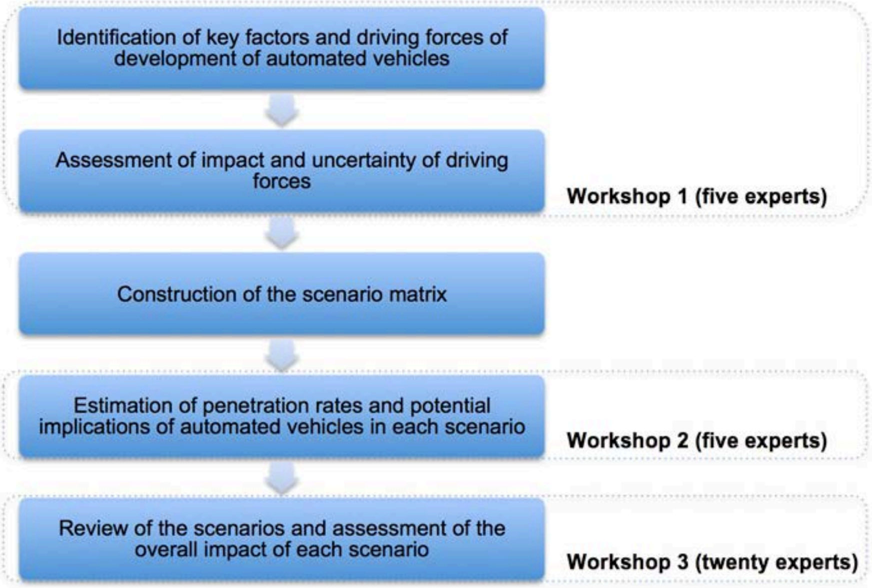


Figure 1. The five steps for the construction and assessment of scenarios about development and implications of automated vehicles in the Netherlands

The process was completed in three experts-based workshops. We approached experts for all three workshops because this is the only real alternative. So far, there has not been carried out (enough) empirical research to be a realistic alternative, and laypersons probably do not have enough insights into penetration rates and effects of automated vehicles. Building a system dynamics model could have been an alternative for parts of our research, but this model would also be based on expert input.

The first two workshops involved five experts (the authors of this paper) from Delft University of Technology (three assistant professors and two full professors). An expert for this study would ideally have a knowledge background on both the technological development and transport implications of automated vehicles. All experts in our study have conducted studies about development and/or implications of automated vehicles. One of the experts has also experience with real world demonstrations of automated vehicles. The background of the experts varies from modelling and assessment of impacts of intelligent vehicles on drivers and traffic, evaluation and design of road networks, optimization and simulation of car sharing systems to land use transport planning and long-term developments in transport in areas such as accessibility, (evaluation of) large infrastructure projects, the environment, safety, policy analyses and ethics.

In the first workshop, the key factors of development of automated vehicles in the Netherlands and the driving forces behind them were determined through a deliberative process. The key factors reflect specific events and general trends related to development of automated vehicles and can be considered as "symptoms resulting from deeper forces" (see Maack, 2001: 69), namely the driving forces (e.g. technology, economy). The SEEPT framework was used to operationalise the possible external forces and help the experts identify connections to the key factors (Maack, 2001). After the discussion, each individual expert was asked to rank the order of the driving forces (lowest to highest) with respect to the magnitude of their potential effect on development of automated vehicles (impact) and the predictability of their future state (uncertainty). A scenario matrix was subsequently drafted based on the two driving forces with the highest median values for impact and uncertainty. Four scenarios were developed around permutations of the two driving forces, as typically suggested in intuitive logics method. Generally, three to five scenarios are considered appropriate for a scenario project to avoid oversimplification and/or unnecessary complexity (Amer et al., 2013).

In the second workshop, the penetration rates of automated vehicles in 2030 and 2050 in the Netherlands, and potential implications for road capacity, value of time and VKT in each of the four scenarios were discussed. After the workshop, a questionnaire was distributed to the participants asking numerical estimations about all issues discussed in the second workshop. These numerical estimations were averaged and incorporated into the storyline of each scenario.

In the last workshop, the four draft scenarios were presented and reviewed by fifteen experts (most of them at executive level) from planning, technology, and research organizations in the Netherlands (e.g. I&M - Ministry of Infrastructure and the Environment, RWS - Ministry of Transport, Public Works, and Water Management, Connekt, KiM - Netherlands Institute for Transport Policy Analysis, RDW - National road traffic agency, Spring Innovation, Eindhoven University of Technology). The fifteen experts hold a wide range of knowledge background associated with the development and implications of automated vehicles. In particular, their disciplinary background included innovation and business planning, forecasting and strategic policy analysis, automated vehicles, automotive human factors and biomechanics, micro-electronics, vehicle type approval, vehicle engineering, traffic management, transport modelling, geography and geoinformatics, accessibility and regional economics. The discussion was organized in two sessions (about (a) development and (b) implications of automated vehicles in the Netherlands respectively) and coordinated by the five experts from Delft University of Technology. All twenty experts also evaluated the scenarios in terms of overall impact (i.e. value of time, road capacity, and total VKT). In the next section, we present the results of each step of this process, ending with the storylines of final scenarios about development and implications of automated vehicles in the Netherlands.

4. Results

4.1 *Key factors and driving forces*

In the first step of our methodology we identified sixteen key factors as critical in shaping future development of automated vehicles in the Netherlands (see Table 1). Each factor could have both direct and indirect effects on the development of automated vehicles. For example, automated vehicle trials could help advance this technology, thus accelerating transition steps towards full automation. Automated vehicle trials could also positively affect the image of automated vehicles to the public, but at the same time they might have a negative influence on those drivers who consider driving automation intrusive.

Table 1. The key factors and drivers of automated vehicles development in the Netherlands as identified in the workshops.

Key factors	Driving forces
AV technology trials	Technology, Policies
Interoperability among AV technologies	Technology, Policies
Costs/benefits of AV technology	Technology, Policies, Customers' attitude
Development of AV in EU	Technology, Policies, Customers' attitude
AV ownership structure (public vs private)	Technology, Economy
Transition steps	Technology, Policies
Incidences	Technology
Energy, emissions	Technology, Policies, Economy, Environment
Legal/institutional context (national and European)	Policies
Public/private expenditures on infrastructure	Policies, Economy
Stability of policies	Policies
Accessibility, social equity	Technology, Policies
Psychological barriers (Citizens and customers)	Technology, Customers' attitude
Marketing/image of AV	Policies, Customers' attitude
Attitudes towards AV	Technology, Policies, Customers' attitude, Economy, Environment
Income	Economy

In the same methodological step, we identified five driving forces behind the key factors. These are policies, technology, customers' attitude, economy and the environment (see Table 1). Policies and technology appear as the driver for twelve and eleven key factors respectively. Customers' attitude and economy were identified as drivers for five key factors. Finally, the environment was identified as a driver of only two key factors.

4.2 *Impact and uncertainty of driving forces*

In the second step of our methodology, we assessed the driving forces with respect to the magnitude of their potential effect on development of automated vehicles (impact) and the predictability of their future state (uncertainty). Thus, each participant was asked to rank the order of the driving forces based on two criteria: impact and uncertainty. According to the results, technology is expected to have the strongest impact on the development path of automated vehicles, but it is also highly unpredictable (see Table 2). Policies were found to be quite influential but uncertain as well. Customers' attitude was also indicated as a highly unpredictable factor, but the expected impact was assumed to be lower than technology and policies. Finally, economy and the environment were assumed to be fairly predictable and to have relatively lower impact on the development of automated vehicles.

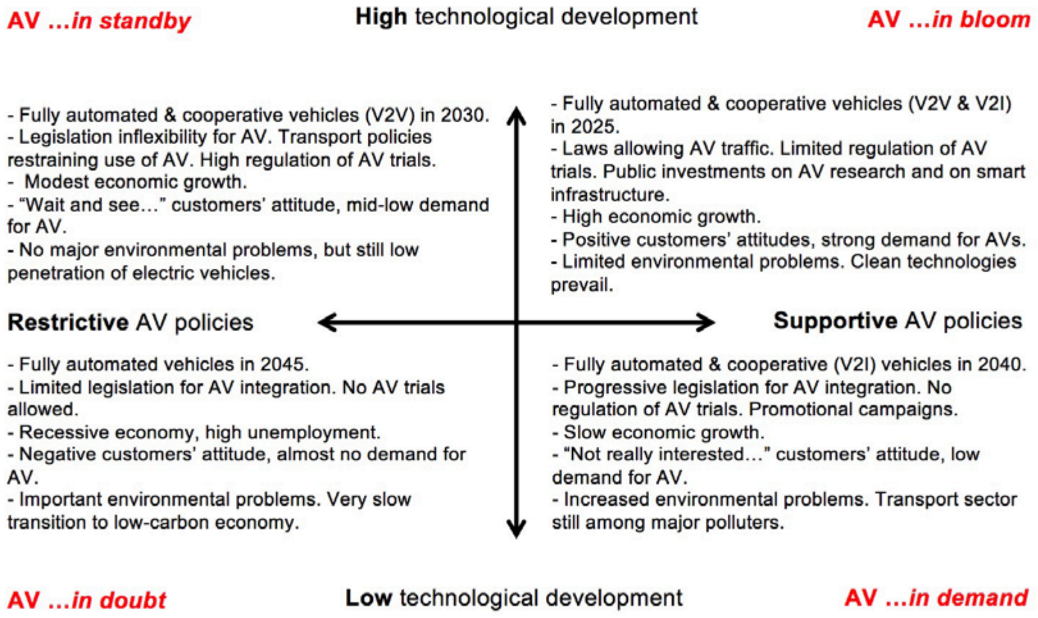
Based on those results, technology and policies appeared to be the most influential driving forces. Both were also highly unpredictable although customers' attitude appeared as an equally uncertain driving force. Therefore, technology and policies were selected as the most relevant driving forces to be used as axes of our scenario matrix. The scenarios were built around permutations of those two forces (high or low technological development and restrictive or supportive policies).

Table 2. The median value of driving forces rank according to their impact and uncertainty (1-lowest, 5-highest). Results from five experts' responses collected in Delft University of Technology workshops.

	Impact	Uncertainty
Technology	5.0	4.0
Policies	4.0	4.0
Customers' attitudes	3.0	4.0
Economy	2.0	2.0
Environment	1.0	1.0

4.3 *Scenario matrix*

Four scenarios were constructed assuming combinations of high or low technological development and restrictive or supportive policies for automated vehicles (AV …in standby, AV …in bloom, AV …in demand, AV …in doubt; see Figure 2). Although scenarios were built around permutations of those two driving forces, we have also incorporated all remaining driving forces in our scenario plots (customers' attitude, economy, environment). The aim was to capture as much as possible of the complexity surrounding this exercise. Moreover, the key factors offered input into the development of distinctive, detailed, dynamic and coherent storylines. The scenario plots are presented in the next four sections.



- Fully automated & cooperative vehicles (V2V) in 2030.
- Legislation inflexibility for AV. Transport policies restraining use of AV. High regulation of AV trials.
- Modest economic growth.
- "Wait and see…" customers' attitude, mid-low demand for AV.
- No major environmental problems, but still low penetration of electric vehicles.

- Fully automated & cooperative vehicles (V2V & V2I) in 2025.
- Laws allowing AV traffic. Limited regulation of AV trials. Public investments on AV research and on smart infrastructure.
- High economic growth.
- Positive customers' attitudes, strong demand for AVs.
- Limited environmental problems. Clean technologies prevail.

- Fully automated vehicles in 2045.
- Limited legislation for AV integration. No AV trials allowed.
- Recessive economy, high unemployment.
- Negative customers' attitude, almost no demand for AV.
- Important environmental problems. Very slow transition to low-carbon economy.

- Fully automated & cooperative (V2I) vehicles in 2040.
- Progressive legislation for AV integration. No regulation of AV trials. Promotional campaigns.
- Slow economic growth.
- "Not really interested…" customers' attitude, low demand for AV.
- Increased environmental problems. Transport sector still among major polluters.

Figure 2. Scenario matrix about development of automated vehicles in the Netherlands.

4.4 *Scenario 1: Automated vehicles …in stand by*

Context

Although discussions about the potential of having fully automated vehicles on public roads by 2030 had been intensified already since 2015 and conditional automation was a reality since 2020, the Dutch government decided not to heavily invest on integration of this mobility technology in the transport system of the Netherlands. In fact, the government did not see any major benefits stemming from a rapid development of automated vehicles, while they did foresee a lot of risks associated with this technology. It is true that the Dutch transport system was really efficient in the early 2020's with a multimodal character, which was translated into a modal split where almost half of the trips were being undertaken by bicycle, foot or public transport. Moreover, transport safety was steadily improving and no major environmental problems were expected in the following years. The consistent strategy towards low-carbon economy had already started paying-off. Also, the modest economic growth did not allow allocation of more resources on infrastructures related to this emerging technology (V2I).

The combination of Dutch government's scepticism about automated vehicles and the weak income growth had possibly played a role on customers' moderate to low demand for automated vehicles. Customers' demand did not significantly change even when conditionally automated vehicles were made commercially available in 2020. The fact that the Dutch government allowed conditionally automated vehicles to travel only in motorways until 2025 might have deterred demand. Moreover, the attitude towards vehicles in general and automated vehicles in particular was not very positive at that time, with most customers adopting a 'wait and see' position. In fact, vehicles usage had reached its peak a decade earlier (during 2010's) mainly because of the generation Y's reluctance to live an automobile oriented -20th century like- life. This attitude did not change dramatically in the following years until the advent of fully automated cars in 2030. At that point automated vehicles (conditional automation) represented a small fraction of total vehicles' fleet (4%) and a slightly higher percentage (7%) of total VKT (see Figure 3).

Penetration rates and impacts

The advent of fully automated vehicles in 2030 signalled a change in customers' attitude. Auto manufacturers adopted an aggressive promotion strategy, which among other actions allowed everyone to experience first hand a fully automated vehicle for a week. They knew that 'hands on' experiences could remove psychological barriers of automated driving from both customers and citizens, even if eventually they would not buy but share a car. Moreover, seamless communication between automated vehicles (V2V) and safe operation in urban environments signalled a huge progress. Operation first of conditionally and then of fully automated vehicles in urban environments was indeed proven to be a real challenge especially with respect to urban intersections and uncontrolled pedestrian movements. Customers' attitudes about automated vehicles became progressively more positive after 2030, which was translated into stronger demand for this kind of vehicles. Twenty years later (2050) automated vehicles represented 26% of the vehicles' fleet and 33% of total VKT (see Figure 3). During the same period (2030-2050) the Dutch government regulated several areas related to fully automated vehicles (e.g. automated-taxis, liability, safety). However, no proactive actions were taken to further promote this mobility technology because initial fears about potential negative implications, such as strong induced travel demand, sprawling trends and a modal shift from conventional public transport to automated vehicles, were confirmed. In fact, the decrease of value of time for automated vehicles users by 21% (see Figure 4) and the increase of motorways capacity by 7% (mainly because of the development of cooperative systems) (see Figure 5) could easily explain the increase of total VKT by 7% in 2050 (see Figure 6).

4.5 *Scenario 2: Automated vehicles …in bloom*

Context

The CEO of Audi predicted in his interview on Automotive News in 2015 that "a vehicle capable of driving itself with no need for any interaction from the driver, even in critical situations, is probably 10 years away" (Automotive News, 2015, February 2). He was right. Technological development between 2015 and 2025 was really fast. First vehicles with conditional automation were already launched in the market in 2018 and fully automated vehicles reached the market in 2025. Governments in the Netherlands, Germany, France, Sweden, UK, Japan and USA helped the research community, high technology industry and auto manufacturers to rapidly push the boundaries of vehicle cooperation (V2V) and automation. In the Dutch context, a progressive regulatory framework for automated vehicles trials was adopted as early as 2016, while significant investments in research and development followed in coming years, supported by

R&D funds of the European Commission. Important investments on vehicles to infrastructure communication (V2I) were decided in mid-2010's and implemented within the next ten years, allowing for seamless operation of automated vehicles in motorways and urban streets but also for easy system upgrades thereafter. Moreover, an aggressive subsidy policy was adopted. During the first five years after launch, fully automated vehicles were exempted from the registration fee, while electric automated vehicles were exempted from road taxes as well. In the case of shared electric automated vehicles (automated taxis) the government decided to provide an additional subsidy of 3000€ on the purchase, which had been proved a successful measure for electric-taxis about a decade earlier. It was clear that the Dutch government was seeing automated vehicles as the solution to many long-standing mobility-related societal problems originated in the 20th century, like congestion and traffic fatalities. They were also considering the introduction of automated vehicles as an opportunity for developing a more efficient multimodal transport system. The healthy macro-economic environment in Europe and the high economic growth in the Netherlands supported the decisions for adopting such aggressive promotional policies for automated vehicles. Moreover, most policy reports from governmental organizations at that time were suggesting that investments on automated vehicles were highly likely to pay-off soon by addressing many of the inefficiencies of the conventional transport system. An important prerequisite, as all reports clearly noted, was user acceptance.

Penetration rates and impacts

Customers' attitude about automated vehicles evolved quite positively during the 2010's. It was the disruptive change in the mobility experience that attracted the attention of most people at that point. More productive use of travel time and safe driving conditions were among the changes that customers valued more. They were also frequently referring to wider positive societal implications such as lower energy consumption, environmental protection, economic, and social equity benefits (e.g. mobility for elderly and disabled persons). The positive economic context, the supportive governmental policies and the wider societal changes of that period such as the growth of digital and shared economy and the environmental awareness movement played also a key role in having strong demand for automated vehicles. The share of automated vehicles reached 11% in 2030 and rocketed to 61% in 2050 (see Figure 3). The share of VKT by automated vehicles in total travel followed a similar path (23% in 2030 and 71% in 2050). As expected, users of automated vehicles (especially early adopters) were inclined to drive, on average, more kilometres than users of conventional vehicles because of the opportunity they had to relax or do other useful things during their trip. Indeed the value of time for users of automated vehicles had dropped 18% already by 2030 and 31% by 2050 (see Figure 4). New models of fully automated vehicles after 2030 offered a highly flexible interior design that allowed all kind of activities to be undertaken during travel including sleeping, working, tele-conferencing and many more. Moreover, the combination of automated and cooperative systems (V2V and V2I) allowed capacity to increase on motorways, regional roads and urban streets by 25%, 10% and 6% respectively in 2050 (see Figure 5). All these benefits did not come without a cost. Total vehicle kilometres had significantly increased by 3% already in 2030 and by 27% in 2050 (see Figure 6). The Dutch government quickly realized that congestion relief would not come simply by introducing automated vehicles. In fact, they realized that congestion could get worse in the future because of induced travel demand and sprawling trends, if they would not take action. Therefore, stricter land use policies inspired by the compact city paradigm (which had been abandoned decades earlier) and transport demand policies, such as road pricing, had been introduced during the 2040s to curb growth in travel and urban expansion. Furthermore, automated taxis had been highly regulated after 2030 with respect to total number of taxis per capita, and hours of operation. Automated taxis were responsible for a significant part of VKT increase and thus congestion, mainly because of their 24/7 non-stop operation. Dynamic policy adaptation, such as in the case of automated taxis (from heavily subsidized to highly regulated), was clearly the right way to go in a new transport ecosystem where frequent, significant and not easily predictable changes were more likely than ever.

4.6 Scenario 3: Automated vehicles …in demand

Context
The optimism for seamless mobility by fully automated vehicles in the near future was high in the mid 2010's. The countless discussions in popular media were centred on possible changes that this technology could bring to daily mobility and subsequently to our societies. These discussions were fuelled by frequent announcements of auto manufacturers' plans for fully automated mobility until 2025. Many governments around the world, including the Netherlands, were foreseeing major societal benefits from this technology, like congestion relief and significant reduction of accidents. Therefore, they rapidly formed progressive legislative frameworks allowing automated vehicles trials and supporting cooperation between automobile and high tech industry. They also invested on research and development of this technology and asked governmental organizations to adapt their plans to possible development of vehicle automation in coming years. Moreover, they secured important resources to fund smart infrastructures that would allow communication with automated vehicles both on motorways and in urban environments (V2I). These investments were partly funded by European Commission R&D funds, which in the meantime had decided to allocate more resources in developing vehicle automation in Europe mainly because of the expected traffic safety benefits.

However, the technological path to full automation was proved more difficult than what was assumed. It took ten years (2025) for auto manufacturers in collaboration with high technology companies only to make conditional automation commercially available. The variability of road infrastructure and weather conditions but also the complexity of urban environment especially with respect to interaction with other road users (conventional cars, cyclists and pedestrians) and to unexpected events (e.g. road flooding) required exhaustive tests and continuous adaptation of technology to meet high safety standards. Moreover, the first fatal accidents in European urban roads between conditionally automated vehicles and pedestrians in 2026 proved that this technology was not entirely ready (at least for urban environments). The European Union and many governments around the world responded with a mandate that conditionally automated vehicles were only allowed on motorways until the technology would evolve enough according to even higher safety standards. The Dutch government also announced a new round of funding for research and development in this area. Fifteen years later (2040) fully automated vehicles were reaching the market.

Penetration rates and impacts
Customers' demand for automated vehicles incrementally increased until 2040 and significantly expanded thereafter. Only 3% of total vehicle fleet was (conditionally) automated in 2030 representing 5% of total VKT (see Figure 3). The first fatal accidents in 2026 further prevented customers from buying automated vehicles. It was only in 2040 with the advent of fully automated vehicles that the psychological barriers for this technology were truly removed and sales subsequently increased. In coming years people realized that this was a safe technology with significant benefits especially with respect to comfort and to various activities someone could undertake during a trip. The value of time was decreased by 16% for automated vehicle users in 2050 (see Figure 4), while penetration was quite high at that time with 17% of all vehicles being automated (see Figure 3). Moreover, capacity increased by 5% in motorways and by 2% in regional roads and urban streets in 2050 (see Figure 5). The combination of a decrease in value of time and an increase in capacity resulted in more VKT in 2050 (3%) (see Figure 6). In fact, the Dutch government was expecting a stronger increase of VKT in coming years after 2050, because penetration of automated vehicles on the market was expected to become even higher. Therefore, they were already planning to introduce travel demand management measures from the

beginning of 2050s to prevent major increase of VKT. Unfortunately, a significant number of automated vehicles were still carrying internal combustion engines. Thus, increased VKT were associated with more energy consumption and more emissions.

4.7 Scenario 4: Automated vehicles …in doubt

Context

Automated driving were one of the most appealing concepts of mobility technology during the 20th century. No accidents, no driving effort, more personal time, less congestion and almost no parking problems were the basic elements of vehicle automation imprinted in the collective imaginary. In the early 21st century, the discussion about the prospects of a fully automated mobility world resurfaced because of some technological progress of auto manufacturers and high technology companies in this area. However, full automation was still way too far from reality and cities and transport systems were more complex than ever. Thus, such a socio-technical transition seemed quite difficult even if technology was available.

In fact, it turned out that none of the basic forces (high technological development, supportive policies and positive customers' attitudes) for such a transition were existent. In a recessive global economic context during late 2010's, most governments (the Dutch included) did not intend to spend their valuable resources on research and on infrastructures for automated vehicles. Neither did they develop a supportive institutional framework for testing and developing this technology. They thought that vehicle automation might, in fact, lead to counter-effective results for the transport system. Their deepest fear was that the system would not evolve enough to become fully automated. Thus, it was likely to be stuck in transition where conditionally automated, fully automated and conventional cars would co-exist, causing major safety and congestion problems especially in urban environments. Their fears were absolutely justified. The technology evolved quite slowly after 2015 with the first conditionally automated vehicles reaching the market only in 2028 and subsequently allowed to travel only on Dutch motorways. The bankruptcy of a major automotive company (due to a sharp decrease in sales of conventional cars in China) and the shift of attention of a high tech giant from automated vehicles to other emerging technologies could partly explain the slow technological development in this field. Technical difficulties associated with the detection of obstacles and navigation in various road and weather conditions and in complex urban environments inhibited rapid technological development as well.

Penetration rates and impacts

Only 1% of total vehicles' fleet was (conditionally) automated in 2030. Customers were reluctant to buy this technology since neither the government supported it through, for example, subsidizing policies, nor middle-class income could afford to pay for such a premium technology. When fully automated vehicles were launched in 2045, customers' interest became stronger since the benefits where clearer then and the Dutch government allowed these vehicles to travel in urban environments as well. However, the price for this technology was still too high, thus fully automated vehicles continued to represent a marginal share of the vehicles' fleet in 2050 (7%). Moreover, fully automated taxis offering premium services became available after 2045. These companies invested in transforming the interior of these taxis into fully functional work and rest spaces. The marginal share of automated vehicles affected neither road capacity nor total VKT in 2050 (see figures 5 and 6 respectively).

Unlike the 20th century, vehicle automation did make it through to the market in the 21st century. However, until 2050 vehicle automation was still a technology for the upper class that could afford it. The rest of the people could have an experience with automated vehicle by hiring an automated taxi or by just taking automated buses, which in the meantime had grown rapidly.

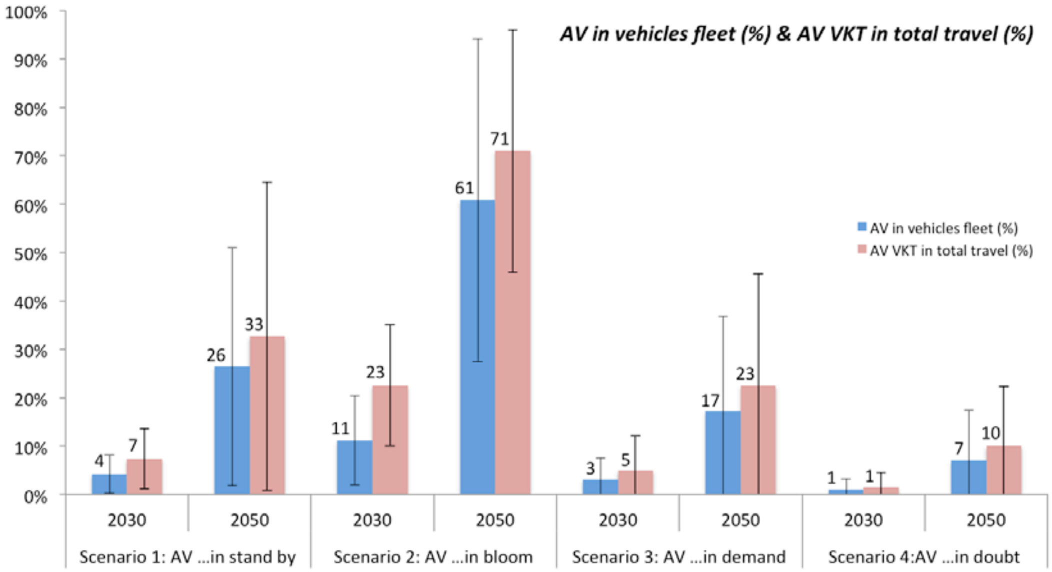


Figure 3. Estimation of (a) percentage of (conditionally and fully) automated vehicles in vehicles' fleet and (b) percentage of VKT by (conditionally and fully) automated vehicles in total VKT, in 2030 and 2050. Each bar represents average value of five experts responses collected in Delft University of Technology workshops and error bar depicts standard deviation.

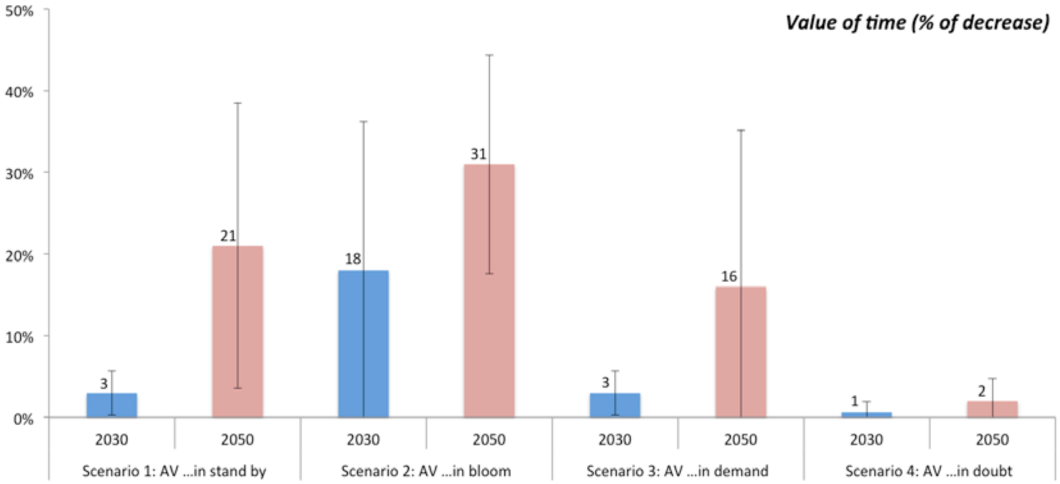


Figure 4. Estimation of decrease in value of time of automated vehicle users in different scenarios. Each bar represents average value of five experts responses collected in Delft University of Technology workshops and error bar depicts standard deviation.

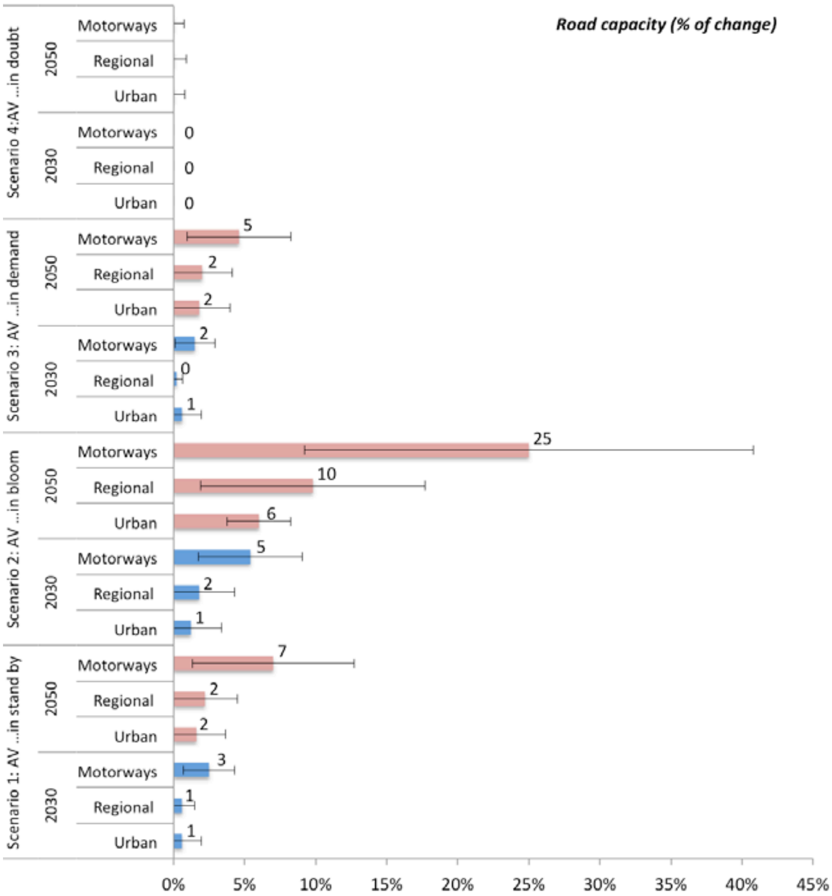


Figure 5. Estimation of capacity changes in different scenarios. Each bar represents average value of five experts responses collected in Delft University of Technology workshops and error bar depicts standard deviation.

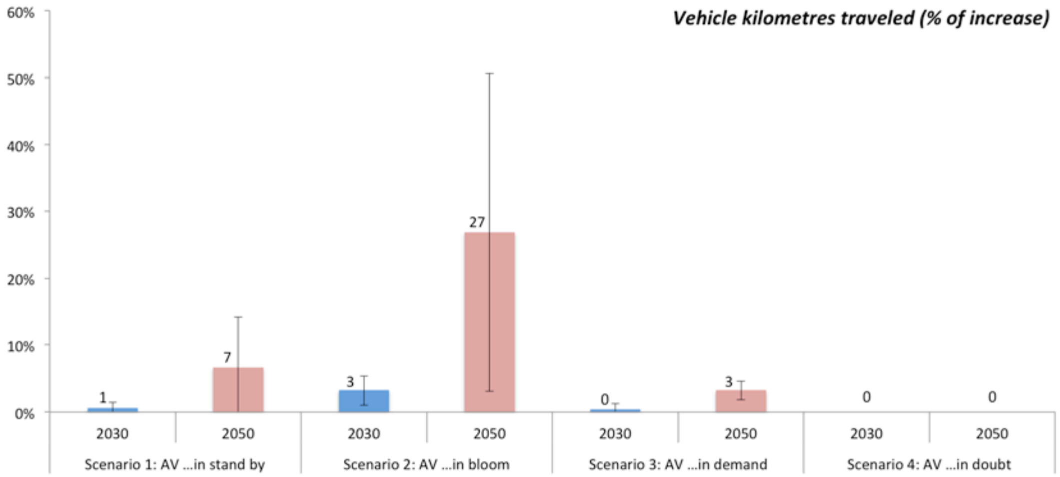


Figure 6. Estimation of change in total vehicle kilometres travelled in different scenarios. Each bar represents average value of five experts responses collected in Delft University of Technology workshops and error bar depicts standard deviation.

4.8 The four scenarios …in brief

Conditionally automated vehicles are expected from our scenarios to be commercially available within a time window of ten years (between 2018 in the 'AV …in bloom scenario and 2028 in the 'AV …in doubt' scenario). The respective time-window for fully automated vehicles is larger (twenty years) and more distant (between 2025 in the 'AV …in bloom' scenario and 2045 in the 'AV …in doubt' scenario) (see table 3). Penetration rates of automated vehicles vary among different scenarios between 1% and 11% in 2030 (see table 4). These rates regard only conditionally automated vehicles except for the 'AV …in bloom' scenario, which anticipates fully automated vehicles to be commercially available well before 2030. Penetration rates are expected to vary between 7% and 61% in 2050. These rates represent penetration of both conditionally and fully automated vehicles. The balance between them in the market has not been quantitatively identified in this study. However, a first rough estimation is described in the scenario plots. The share of automated vehicles VKT in total travel varies along similar ranges (between 1% and 23% in 2030 and between 10% and 71% in 2050).

Expected impacts of automated vehicles on mobility show great variation among the four scenarios as well. For example, the decrease in the value of time for automated vehicle users varies between 1% and 18% in 2030 and between 2% and 31% in 2050. Similarly, capacity changes of motorways vary between 0% and 5% in 2030 and between -3% and 25% in 2050. Moreover, expected changes in the capacity of urban roads vary between 0% and 1% in 2030 and -1% and 6% in 2050. Finally, total VKT change varies between 0% and 3% in 2030 and between 0% and 27% in 2050. The highest impacts appear in the 'AV …in bloom' scenario and the lowest in the 'AV …in doubt' scenario.

Table 3. Market introduction year for conditionally and fully automated vehicles according to different scenarios.

	First vehicle in the market	
	Conditionally automated	Fully automated
AV …*in stand by*	2020	2030
AV …*in bloom*	2018	2025
AV …*in demand*	2025	2040
AV …*in doubt*	2028	2045

Table 4. Range of penetration rates and impacts of automated vehicles in the four scenarios.

	2030		2050	
	Min	Max	Min	Max
AV in vehicles' fleet (%)	1	11	7	61
AV VKT in total travel (%)	1	23	10	71
Value of time - AV users (%)	1	18	2	31
Capacity (%)				
Motorways	0	5	-3	25
Regional roads	0	2	0	10
Urban roads	0	1	-1	6
Total VKT (%)	0	3	0	27

4.9 Validation and overall impact of the scenarios

In the last workshop, the four draft scenarios were presented and reviewed by fifteen experts. The experts validated the scenarios by assessing them as logically consistent and plausible. Moreover, all scenarios were assessed with respect to their overall impact. All participants to the last workshop were asked to evaluate each scenario with respect to its overall impact (i.e. on value of time, road capacity, and total VKT) on a scale ranging from 0 (no impact) to 5 (highest impact). The participants were also asked to respond about their confidence with the estimations on a scale ranging from 0 (not at all confident) to 5 (very confident).

Scenario 2 (AV …in bloom) was expected to have the highest overall impact (4.6), with scenario 1 (AV …in standby) and scenario 3 (AV …in demand) having similar but lower effects (2.4 and 2.3 respectively) (see Figure 7). Scenario 4 (AV …in doubt) was not expected to have significant impacts on mobility (1.1). The participants were quite confident about their responses (average level of confidence: 3.1). The results did not change significantly when responses were weighted based on the level of confidence. Moreover, standard deviation of assessments for scenario 2 (AV …in bloom) was the lowest compared to all other scenarios showing a convergence in the opinions of experts about potential impacts of this scenario.

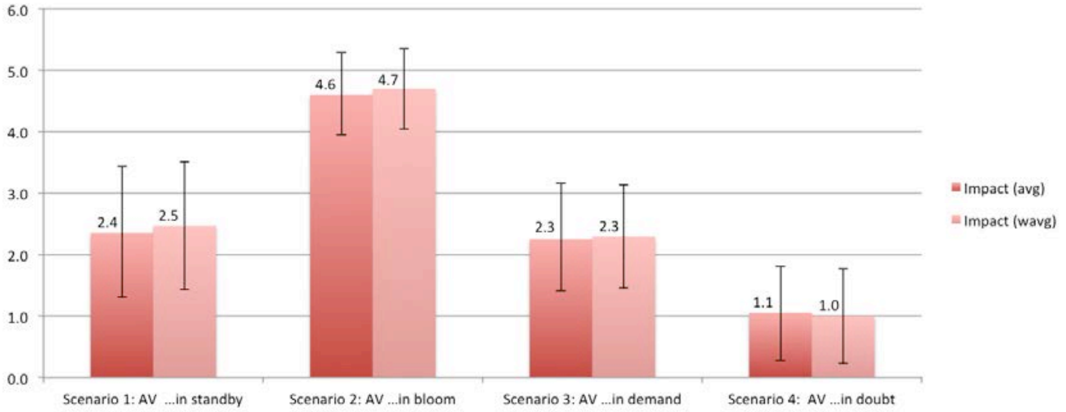


Figure 7. The average values of twenty experts responses on the overall impact (i.e. value of time, road capacity, and total VKT) of the four scenarios about development of automated vehicles in the Netherlands. Weighted average values are based on the participants' level of confidence. Error bars depict standard deviation.

5. Conclusions

The aim of this study was to identify plausible future development paths of automated vehicles in the Netherlands and to estimate potential implications for traffic, travel behaviour and transport planning on a time horizon up to 2030 and 2050. To this end, a scenario analysis was conducted. Technology and policies were assessed to be the most influential and unpredictable driving forces; hence the scenario matrix was built around them. Four scenarios were constructed assuming combinations of high or low technological development and restrictive or supportive policies for automated vehicles. All remaining driving forces (customers' attitude, economy and the environment) have been incorporated in the scenarios as well.

According to the scenario analysis:

- fully automated vehicles are expected to be commercially available within a time window of twenty years (between 2025 and 2045), while the respective time-window for conditional automation is smaller (ten years) and more immediate (between 2018 and 2028),
- public (national, EU) and private (OEMs) R&D investments, progressive regulatory frameworks (e.g. trials, subsidies) as well as increased customers' demand could accelerate transition from conditionally to fully automated vehicles,
- full vehicle automation is expected to be a game changer, driving the demand for automated vehicles to a high point. Penetration rates of automated vehicles on the market are expected to vary among different scenarios between 1% and 11% (mainly conditionally automated vehicles) in 2030 and between 7% and 61% (mainly fully automated vehicles) in 2050,

- vehicle automation and cooperation are expected to follow converging evolution paths. The type of cooperation (V2I, V2V) will likely vary among different scenarios according to the main drivers (policies, technological development),
- complexity of urban environment is expected to influence the development path of automated vehicles either by inducing regulation allowing automated vehicles to travel only on motorways or by complicating and subsequently delaying technological development in this field,
- unexpected incidents like fatal accidents; bankruptcy or change in strategic priorities of major industry players could significantly influence the development path for automated vehicles in the Netherlands,
- development of automated vehicles is expected to have implications on mobility in all scenarios. These implications vary from very important in the 'AV …in bloom' scenario to minimal in the 'AV …in doubt' scenario,
- capacity in motorways is expected to increase between 0% and 5% in 2030 and vary between -3% and 25% in 2050. This result is consistent with estimations of studies showing capacity increases of more than 10% for a 40% penetration rate of cooperative adaptive cruise control (CACC) (Arnaout & Bowling, 2011; Shladover et al., 2012),
- capacity benefits are expected to be higher in motorways than in urban streets. Urban intersections as well as interaction of automated vehicles with other road users (e.g. cyclists, pedestrians) are among the reasons for this difference,
- total VKT is expected to increase between 0% and 3% in 2030 and between 0% and 27% in 2050. Earlier travel demand studies have shown that total VKT could increase between 4% and 26% after introduction of automated vehicles (Milakis et al., 2016),
- the Dutch government is expected to take measures (e.g. travel demand management) to curb growth of travel and subsequent externalities in three out of the four scenarios.

In the last step of our study fifteen experts validated the scenarios by assessing them as logically consistent and plausible. Moreover, all twenty experts assessed the overall impact of all scenarios (i.e. value of time, road capacity, and total VKT). The experts responses converge that 'AV …in bloom' scenario will possibly have the highest and the 'AV …in doubt' scenario the lowest overall impact.

We finally discuss the importance of the Dutch policy and transport system context, firstly to explore if the rather positive opinions about automated vehicles in our study match this context, and secondly to provide a first step in understanding the relevance of our findings for other countries.

With respect to Dutch transport policies, an important factor could be that the Dutch minister (at the time of doing this research, 2015) announced she supports the introduction of automated vehicles in the Netherlands. This follows the initial supportive actions of earlier Dutch transport ministers during the second half of the nineties (see Coëmet *et al.*, 1998). In November 2013, she stated she expected that in twenty years (from 2013) all cars driving on Dutch roads would drive automatically, and that, if needed, regulations would be implemented to realize this, mainly for safety reasons (Benschop, 2013). Of course future ministers and politicians can have other opinions, but so far there is political support for the introduction of automated vehicles. In line with her announcement we are aware of the existence of technical teams at the Dutch Ministry of Infrastructure and the Environment studying the topic of automated vehicles and related policies (see e.g. Tillema et al., 2015).

But will the positive policy support maintain? In 1988 the Netherlands was one of the first countries worldwide to announce the introduction of a national system of road pricing on motorways. Several alternatives were proposed, the most recent one being a per kilometre charge. But so far none of the plans was introduced, whereas other countries, where the debate started later, did introduce such policies. For example, Germany introduced the LKW-Maut system (charging lorries on motorways) and London introduced the congestion-charging scheme several years ago. The Netherlands has the reputation of announcing innovative policies but not implementing them so easily.

With respect to the characteristics of the transport system it is important to realize that the Netherlands has a relatively dense motorway network. Even for many intra-regional trips car drivers make use of motorways. Because motorways are probably the first where automated vehicles will be introduced, this characteristic of the Dutch road network is important. On the one hand it might be a factor positively influencing the introduction of automated vehicles because a large share of kilometers driven on motorways results in relatively large benefits of automated vehicles. But on the other hand it could be a barrier, because the Dutch motorways are heavily used (high intensities) and there are many on and off ramps, making the motorway system relatively complicated from a user perspective. This barrier could be reduced if automated vehicles could be spatially separated from other vehicles on separate lanes. Another potential enabler is the fact that Dutch national policies traditionally focus way more on the main road network, as opposed to local or regional roads – these are the responsibility of provinces and local municipalities. Moreover, reducing congestion on motorways has been an important aim of national policies for decades. Especially if automated vehicles are expected to not only reduce accident rates, but also congestion, this may positively influence support of policy makers and the wider society for the introduction of automated vehicles, at least on motorways.

In conclusion, our study suggests that according to the experts fully automated vehicles are expected to be a reality between 2025 and 2045 and to have significant implications for mobility and planning policies in the Netherlands. The pace of development and subsequent implications largely depend on technological evolution, policies and customers' attitude. Other countries might have different driving forces or the same driving forces could be weighted differently with respect to their impact and uncertainty. For example, customers' attitude instead of policies might be assessed as a more influential force for development of automated vehicles in the US context. The driving forces might also be weighted differently if the focal question was different. For example, the recent national foresight study in the Netherlands identified the economy as one of the driving forces for mobility (Snellen et al., 2015). The economy was not assessed as a critical factor for the development of automated vehicles in our scenario exercise compared to other factors such as the technology.

Our scenario design team consisted of experts with a background on transport, from a variety of disciplines (i.e. civil engineering, human factors, planning, geography). The results of the scenario exercise were also validated from an additional group of experts with wider range of backgrounds. Nevertheless, we cannot exclude the possibility that participation of additional experts from other disciplines (e.g. technology, economy) in the scenario design team might have changed some aspects of the scenario storylines. Moreover, it is important to keep in mind that the scenario paths we identified for the development of automated vehicles are plausible but not the only ones. These paths describe futures that might come true or not. What is useful to read from those scenarios is (a) what factors could have a major influence on the future of automated vehicles in the Netherlands and (b) what factors might be useful to monitor to anticipate specific changes and impacts on the urban and transport systems from this new mobility technology. Moreover, these scenarios could help assess the robustness of potential transport investments and/or policies in the Dutch context, for example through sensitivity analysis in cost-benefit analysis.

Our impact assessment exercise offers a rough order of magnitude estimate of the possible impacts of automated vehicles on transport demand in various scenarios based on experts' responses. In fact, estimations varied greatly among the experts as indicated by the high standard deviations in figures 3 to 6. Such deviating estimates reflect the uncertainty associated with potential impacts of automated vehicles on transport. We chose to ask experts to indicate their estimates based on a questionnaire after the group discussion to allow for possible variation in their estimates instead of 'forcing' consensus. The use of average estimates within our storylines should not be read as an indication of certainty. Average estimates rather serve the need for distinctiveness and consistency in our scenario storylines. Experts' estimations about penetration rates of vehicle automation and/or value of time in different scenarios can offer input to subsequent modelling exercises to explore impacts on travel demand more precisely (see Milakis *et al.*, 2016 for a detailed review of modelling studies assessing various impacts of automated vehicles). Sensitivity analysis in these exercises could address uncertainty about the magnitude of those effects.

Finally, we should keep in mind that wider implications of vehicle automation on other transport modes (i.e. public transport, bicycle, pedestrians and trucks) as well as on the environment, safety, economy, social equity and public health are possible (see Milakis et al, 2016). Such implications were out of scope for this study, but could be significant. For example, shared automated vehicles could challenge the viability of traditional public transport by attracting users seeking more flexible travel. Moreover, automated vehicles could replace to some extent active modes for short distance trips or egress/access trips to public transport. On the other hand, people might still prefer active modes for exercise, health and socializing reasons. Such questions about implications of automated vehicles to the wider transport system still remain open.

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