Scenarios about development and implications of automated vehicles in the Netherlands

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Submitted for presentation to the 95th Annual Meeting of the Transportation Research Board

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6235 Words + 5 Figures + 2 Tables = 7985 Words
ABSTRACT

Automated driving technology is emerging. Yet, less is known about when automated vehicles will hit the market, how penetration rates will evolve and to what extent this new transportation technology will affect transportation demand and planning. This study identified through scenario analysis plausible future development paths of automated vehicles in the Netherlands and estimated potential implications for traffic, travel behavior 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 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. It is expected that measures to curb growth of travel and subsequent externalities will be necessary in three out of the four scenarios.

Keywords: Automated vehicles, scenarios, development, implications, The Netherlands
INTRODUCTION

The introduction to the market, the development and the implications of automated driving are among the main uncertainties of the future transport system. According to Milakis et al. (1) automated vehicles could have significant impacts on cities and transportation systems. The design of robust long-term transport policies and investments needs to take into account uncertainties associated with automated vehicles. The aim of this study is to identify plausible future development paths of automated vehicles in the Netherlands and to estimate potential implications for traffic, travel behavior and transport planning on a time horizon up to 2030 and 2050.

The 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 in this development can be distinguished?
- 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 behavior?
- To what extent might automated vehicles affect transportation planning?

The rest of this paper is structured as follows. The literature review is firstly presented. Then we describe our methodology and we present four scenarios about the development and possible effects of automated vehicles in the Netherlands. We close this paper with our conclusions.

LITERATURE REVIEW

Development of automated vehicles

The development of automated vehicles takes place along two axes. First, the manual to automated axis that describes the extent to which the human driver monitors the driving environment and executes aspects of the dynamic driving task. Second, the autonomous to cooperative axis that describes the extent to which vehicles can communicate and exchange information with other vehicles (V2V) or with the infrastructure (V2I). For the manual-to-automated axis, two main taxonomies that classify the levels of vehicle automation have been identified (2, 3). In both taxonomies the first three levels assume that a human driver will control all driving tasks. The remaining levels assume that an automated driving system takes control of all dynamic tasks of driving. In our scenario study we use the NHTSA (2) taxonomy for vehicle automation. We refer to level 3 and level 4 as ‘conditional’ and ‘full’ automation respectively. In conditional automation the driver is expected to be available for occasional control of the vehicle while in full automation s/he is not. Full automation comprises both occupied and unoccupied vehicles. According to a survey held during the Automated Vehicles Symposium 2014, experts expect conditionally, and fully automated vehicles to hit the market in 2019 and 2030 respectively (median values) (4). Litman (5) estimated the penetration rate of fully automated vehicles assuming that they will hit 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 vehicles dominate the
car sales market and another ten to twenty years before the majority of travel is done using automated vehicles. Moreover, Kyriakidis et al. (6) reported that 69% of the respondents in their internet-based questionnaire survey expected fully automated vehicles to reach 50% penetration rate up to 2050.

Impacts of automated vehicles on road capacity, travel behavior and transport infrastructures

Automated vehicles could enhance road capacity by optimizing driving behavior with respect to time gaps, speed and lane changes (7). 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). These studies indicate that ACC can either have a small negative or a small positive effect on capacity (-5% to +10%) (see e.g. 8, 9). For CACC, most studies report a quadratic increase in capacity as the penetration rate increases, with a theoretical maximum increase of 100% (doubling). These studies indicate that the increase in capacity is high (>10%) only if the penetration rate is higher than 40% (see e.g. 10, 11, 12).

The effect of automated vehicles on travel behavior is a relatively less researched topic. Malokin et al. (13) showed that the ability of multitasking in automated vehicles could increase driving alone and shared ride commute shares by 1% each. Gucwa (14) applied several scenarios of potential changes in value of time because of introduction of automated vehicles in San Francisco. He found an increase in vehicle kilometers traveled (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 (15, 16).

The introduction of automated vehicles could reduce the requirements for road network expansion in the future because of the increases in road capacity. Estimations about the magnitude of this reduction vary from substantial (17) to only marginal because of the possibility of induced travel demand (5, 18, 19). Automated vehicles could also challenge the role of public transport (buses in particular) in the future transport system (5, 20). Finally, increases in road capacity may create the opportunity for development of bicycle and pedestrian infrastructures (i.e, bicycle lanes or wider sidewalks).

METHODS

Given the uncertainty and the long-term character of our research questions, 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” (21). 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 (21). According to Maack (22) and Townsend (23) scenarios should be plausible, distinctive, consistent, relevant, creative, and challenging.

Whilst methodologies for scenario construction show great variation, there is a basic common underlying structure (see 22, 24, 25). In our study, the scenario development process involved five sequential steps: (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 likelihood and overall impact of each scenario.

The process was completed in three workshops. The first two workshops involved five experts (the authors of this paper) from Delft University of Technology. In the first workshop, we identified the key factors of development of automated vehicles in the Netherlands and the driving forces behind them. Each expert was also asked to rank 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). A scenario matrix was subsequently drafted based on the results of the first workshop. In the second workshop, we discussed 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. After the workshop, a questionnaire was distributed to the participants asking numerical estimations about all issues discussed in the second workshop.

In the last workshop, the four draft scenarios were presented and reviewed by fifteen experts 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 discussion was organized in two sessions ((a) development and (b) implications of automated vehicles in the Netherlands) and was coordinated by the five experts from Delft University of Technology. All twenty experts also evaluated the scenarios in terms of likelihood and overall impact (i.e., value of time, road capacity, and total VKT).

**RESULTS**

**Key factors and driving forces**

Sixteen key factors and five driving forces behind them (policies, technology, customers’ attitude, economy and the environment) were identified as critical in determining future development of automated vehicles in the Netherlands (see Table 1). The driving forces were assessed with respect to the magnitude of their potential effect on development of automated vehicles (impact) and the predictability of their future state (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 equally uncertain driving force. Therefore, technology and policies were selected as the most relevant driving forces to build our scenario matrix.
TABLE 1 Key Factors and Drivers of the Development of Automated Vehicles in the Netherlands.

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

TABLE 2 Ranking (Median Values) of Driving Forces of the Development of Automated Vehicles (AV) According to their Impact and Uncertainty (1-Lowest, 5-Highest).

<table>
<thead>
<tr>
<th>Driving forces</th>
<th>Impact</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Policies</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Customers’ attitudes</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Economy</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Environment</td>
<td>1.0</td>
<td>1.0</td>
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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 1). Although scenarios were built around permutations of those two driving forces, we 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 detailed, dynamic and coherent storylines. The scenario plots are presented in the next four sections.
Although discussion 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 transportation 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 transportation 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 transportation. Moreover, transport safety was steadily improving and no major environmental problems were expected in 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 skepticism 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 use had already reached its peak a decade earlier (during 2010’s) mainly because of the generation Y reluctance to live an automobile oriented 20th century like life. This attitude did not change dramatically in the following years until the

FIGURE 1: Scenario matrix about development of automated vehicles in the Netherlands.

**Scenario 1: Automated vehicles ...in stand by**

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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 2).

The advent of fully automated vehicles in 2030 signalized 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 the car. Moreover, seamless communication between automated vehicles (V2V) and safe operation in urban environments signaled a huge progress. Operation first of conditional and then of fully automated vehicles in urban environments was indeed proven 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 vehicles fleet and 33% of total VKT (see Figure 2). 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, like strong induced travel demand, sprawling trends and a modal shift from conventional public transportation to automated vehicles were confirmed. In fact, the decrease of value of time for automated vehicles users by 21% (see Figure 3) and the increase of motorways capacity by 7% (mainly because of the development of cooperative systems) (see Figure 4) could easily explain the increase of total VKT by 7% in 2050 (see Figure 5).

Scenario 2: Automated vehicles ...in bloom

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”. He was right. Technological development between 2015 and 2025 was really rapid. First vehicles with conditional automation were already launched in the market in 2018 and fully automated vehicles hit the market in 2025. Governments in the Netherlands, Sweden, UK, Japan and USA helped 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 infrastructure communication with vehicles (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 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 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 transportation 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 transportation system. An important prerequisite, as all reports clearly noted, was user acceptance.

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, but also 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 2). The share of VKT by automated vehicles in total travel followed a similar path (23% in 2030 and 71% in 2050). As expected, automated vehicles users (especially early adopters) were inclined to drive, on average, more kilometers 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 automated vehicles users had dropped 18% already by 2030 and 31% by 2050 (see Figure 3). 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 both motorways and urban streets by 25% and 6% respectively in 2050 (see Figure 4). All these benefits did not come without a cost. Total vehicle kilometers had significantly increased by 3% already in 2030 and by 27% in 2050 (see Figure 5). 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 transportation 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 transportation ecosystem where asymmetric changes were more likely than ever.
Scenario 3: Automated vehicles ...in demand

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 centered on possible changes that this technology could bring to daily mobility and subsequently to our societies. These discussions were fueled 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 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 hitting the market.

Customer’s demand for automated vehicles incrementally increased up to 2040 and significantly expanded thereafter. Only 3% of total vehicle fleet was (conditionally) automated in 2030 representing 5% of total VKT (see Figure 2). 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 when 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 3), while penetration was quite high at that time with 17% of all vehicles being automated (see Figure 2). Moreover capacity increased by 5% in motorways and by 2% in urban streets in 2050 (see Figure 4). The combination of a decrease in value of time and an increase in capacity resulted in more VKT in 2050 (3%) (see Figure 5). In fact the Dutch government was expecting a stronger increase of VKT in coming years after 2050, because penetration of
automated vehicles 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 portion of automated vehicles was still carrying internal combustion engines. Thus, increased VKT were associated with more energy consumption and more emissions.

Scenario 4: Automated vehicles ...in doubt

Automated vehicles 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 transportation systems were more complex than ever. Thus, such a socio-technical transition seemed quite difficult even if the 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 transportation system. Their deepest fear was that the system would not evolve enough to become fully automated. Thus, it was likely to stuck in transition where semi-automated, fully automated and conventional cars would coexist, causing major safety and congestion problems especially in urban environments. Their fears were absolutely justified. The technology evolved quite slowly after 2015 with first conditional automation vehicles hitting 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.

As a result 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 have invested in transforming the interior of these taxis into fully functional work and rest spaces. The marginal share of automated vehicles affected neither capacity nor total VKT in 2050.
Unlike 20th century, vehicle automation did make it through to the market in 21st century. However, until 2050 automated vehicles was still a technology for the upper class that could afford to have 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 2 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 3 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 4 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 5 Estimation of change in total vehicle kilometres traveled 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.
Likelihood and overall impact of the scenarios

All scenarios were assessed with respect to their likelihood and overall impact during the last workshop. The participants were asked to evaluate each scenario with respect to (a) its likelihood, on a scale ranging from 0% (impossible) to 100% (certain), and (b) 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).

According to the results, scenario 2 (AV …in bloom) and scenario 3 (AV …in demand) were perceived as the most likely to happen in the future (41.8% and 38.3% respectively). The likelihood of scenario 1 (AV …in standby) and of scenario 4 (AV …in doubt) was assessed lower (31.8% and 25.8% respectively). The average sum of probabilities per person was 137.5%, while only one person estimated a sum of probabilities below 100%. Moreover, 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.

The scenario 2 (AV …in bloom) was also 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). The scenario 4 (AV …in doubt) was not expected to have significant impacts on mobility (1.1).

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 behavior 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 our scenarios as well.

According to our 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),
- full vehicle automation will likely be a game changer, driving the demand for automated vehicles high. Penetration rates of automated vehicles 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 will likely follow converging evolution paths. The type of cooperation (V2I, V2V) will likely vary though among different scenarios according to the main drivers (policies, technological development),
- complexity of the urban environment is expected to influence the development path of automated vehicles either by inducing regulation allowing automated vehicles to travel only in 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 not only in the Netherlands, but also in any country,

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,

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 twenty experts assessed the likelihood of all
scenarios and overall impact (i.e., value of time, road capacity, and total VKT).
Scenario 2 (AV …in bloom) and scenario 3 (AV …in demand) were perceived as the
most likely to happen in the future, while likelihood of scenario 1 (AV …in standby)
and scenario 4 (AV …in doubt) was assessed lower. The results show that these
experts expect policies in the Netherlands to be generally supportive of automated
vehicles (scenarios 2 and 3 exhibited the highest likelihood). Thus, it is probably
technology that will mainly influence development path of automated vehicles. In
fact, participants seem also to believe that technology has good chances to develop
rapidly and full automation to be a reality within the next ten years, if we take into
account that ‘AV …in bloom’ was ranked as the most likely scenario. It should be
noted that the average sum of probabilities per participant was 137.5%, while only
one person estimated a sum of probabilities below 100%. This indicates that the
participants were quite confident that the four scenarios can adequately describe
potential development paths of automated vehicles in the Netherlands or at least they
did not consider an alternative fifth scenario as more likely. Finally, the experts
expect the ‘AV …in bloom’ scenario to have the highest and the ‘AV …in doubt’
scenario the lowest overall impact.

In conclusion, our study suggests that fully automated vehicles will likely be a
reality between 2025 and 2045 and are expected 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. These driving forces could be weighted differently in other
countries or from other experts with respect to their impacts and uncertainty. Thus,
the paths we identified for the development of automated vehicles in this study are
plausible but not the only ones. Moreover, our assessment exercise offers a rough
order of magnitude estimate of the possible impacts of automated vehicles in various
scenarios based on experts’ responses. Such estimations can offer input to subsequent
modeling exercises to explore these impacts and their complex interactions more
precisely. Sensitivity analysis in these modeling exercises could address uncertainty
about the magnitude of those effects.

ACKNOWLEDGEMENTS

This research was funded by the PBL Netherlands Environmental Assessment
Agency.
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