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Preface

CARTRE, Coordination of Automated Road Transport Deployment for Europe, is a Support Action submitted for the call H2020-ART-2016-SingleStage-RTD. CARTRE aims to accelerate development and deployment of automated road transport by increasing market and policy certainties. To achieve this, CARTRE will support the development of clearer and more consistent policies for EU Member States in collaboration with industry players, ensuring that automated road transport systems and services are compatible at EU level and are deployed in a coherent way.

Task 5.2 of CARTRE (Coordination of Automated Road Transport Deployment for Europe) focused on the socio-economic impact assessment of automated driving and had this deliverable (5.3) as its outcome.

CARTRE is a network of European experts in the area of automated driving. The partners of this specific task, representing industry, research and road authorities, were called to discuss and assess the potential societal impacts of automation in a structured approach. The work was built on the work of the Trilateral ART Working Group (Innamaa et al 2018), in particular – Impact areas identified in that group and key performance indicators (KPIs) suggested.

A scenario-based assessment was selected as the approach. Seventeen experts from thirteen organizations shared responsibilities in the study and provided independent impact estimates for eight impact areas in potential future service scenarios. Based on the individual work of the experts, a group consensus of estimates was reached when feasible.

For making the estimates, several assumptions were needed regarding services, the maturity of technology, automation penetration, etc. Therefore, the focus of the work was on comparing the effects, not absolute estimates. The group highlighted the uncertainty of the figures presented; many empirical studies will be needed to provide reliable estimates and to validate the findings. The outcome has the format of a working paper representing the current opinion among a limited number of experts.

In addition to numerical comparisons, the report provides qualitative data on KPIs and reasoning of impacts, which we hope will provide a valuable contribution to further activities in the field of impact assessment.

Finally, the report also provides some insight into what is expected from ongoing studies in Europe in terms of socio-economic impacts.

Contents

1. Executive summary

This deliverable summarizes discussions by the partners involved in CARTRE task 5.2 on the socio-economic impacts of automated car driving. The group consisted of twelve experts/organizations representing industry, research and road authorities. The work was built on that of the Trilateral ART Working Group: the impact areas and key performance indicators (KPIs) used here were selected by taking their outcomes as a starting point. For each KPI of the selected outcome it was discussed what the beneficial/targeted direction of change would be from a societal perspective, and what would be the factors affecting the KPIs.

The approach was a scenario-based assessment aimed at comparing the impacts of four potential future scenarios created for the assessment. One of the scenarios was a short-term scenario in which the focus was on gradual extrapolation of automated services, and the rest were long-term. The first of the long-term scenarios described a transport system in which automation emerges parallel to shared mobility, and the fleets of automated vehicles are market operated. The second long-term scenario pictured a future in which shared automated transportation is authority driven. In the third long-term scenario, automated vehicles are mostly privately owned and shared mobility has not succeeded.

The experts shared responsibilities in the study and provided impact estimates, relative in nature, for eight impact areas in the four scenarios. It was also discussed how certain the experts felt about the assumed impacts of automation. As a result, scenario-based estimates of automated driving were defined for use and acceptance, mobility and travel behaviour, public health and safety, land use and economic analysis impact areas. For assessment of some impact areas, the experts found it more suitable to define more detailed AD service descriptions within which the estimates were given for driver behaviour, energy and environment and network efficiency.

The scenario-based assessment suggests that in the short term, the impacts of automated driving would be minor or moderate. Most substantial short-term impacts were assessed for user acceptance and use, but also some costs were expected already in the short term. In the assessment of the long-term scenarios, the scenario in which the focus was on automated public transport appeared to be the most beneficial one for most of the impact areas. Overall, the two scenarios that included shared mobility showed the most benefits from automated driving. However, the scenario of privately-owned automated vehicles was assessed as the best one in terms of economic impacts.

This work also includes mapping of ongoing or very recent projects studying driving automation in Europe. Information about these projects was collected by sending a template to the experts involved in the studies. The input indicating which KPIs are going to be covered was received from 11 projects and the expected output of the projects was mapped by impact area. The discussion on how certain the experts were about the impacts was compared with what is expected from ongoing and recent studies. Based on the mapping, expectations from ongoing studies are quite high – all topics identified are, it seems, being studied to some degree. The results, however, do not indicate how comprehensive the outcomes are expected to be.

In conclusion, it was agreed by the group that driving automation has the potential to benefit society in many ways but drawbacks are also expected. The results suggest that policy instruments and e.g. the use of shared mobility shape the impacts of automated driving considerably.

Lastly, the outcome of this work should be considered as a paper that encourages discussion, not as a final answer. It is important to discuss what the desirable future with automated driving is and how it can be achieved. At the same time, it is evident that a lot of empirical studies are needed. Hopefully, this paper raises some of the most critical questions regarding societal impacts of automated driving for further discussion.

2. Introduction

Vehicle automation has the potential to transform the road transportation system. While new driving automation technologies are one of the most discussed topics in the transport sector, the socio-economic impacts of automated driving are largely unknown and thus require comprehensive research. Several ongoing projects are assessing automated driving in different ways – from very detailed field tests to more general reviews. In this study, we made a scenario-based expert assessment of the impacts of automated driving, providing insight into what the impacts in the selected scenarios could be. The study described potential development paths, and provided an initial assessment of the impacts and the factors affecting them. The results are tentative estimates that should be verified in further empirical studies.

When defining a scenario, values are given for a set of parameters. Geels and Schot (2007) presented a general model on multi-level transitions of a socio-technical regime (Figure 1). The model differentiates between three levels: the socio-technical landscape, socio-technical regime and niche innovations, and provides a generic structure of how different levels interact with each other in transitions.

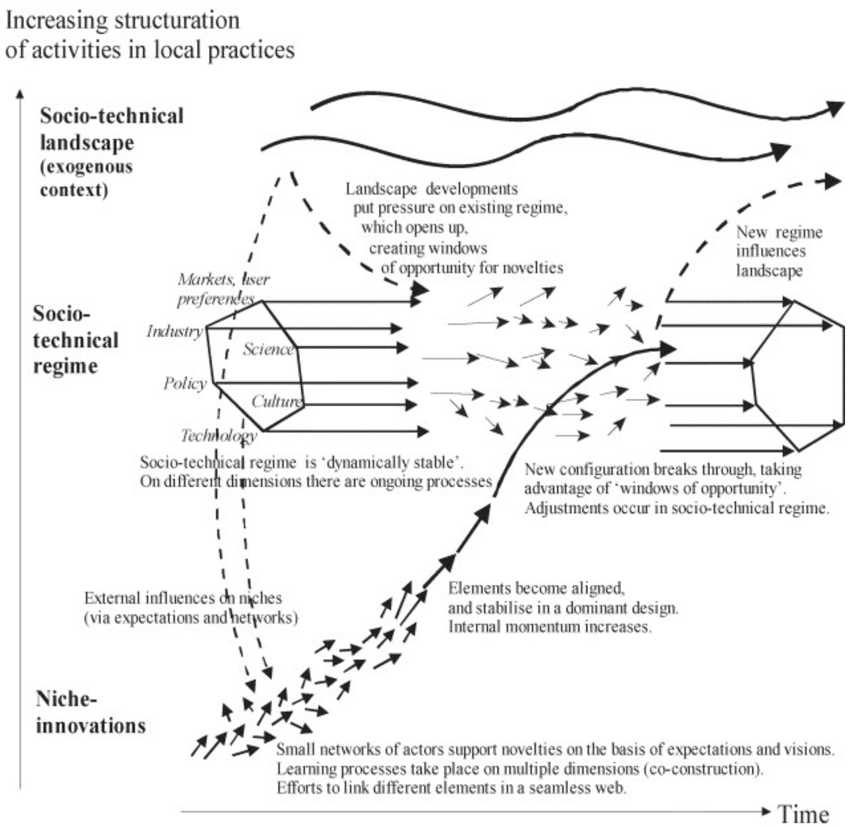


Figure 1. Geels & Schot 2007: Multi-level perspective on transitions (adapted from Geels, 2002, p. 1263).

In the context of automated driving, the socio-technical regime would be the whole road transport system, which encompasses industry, policy, technology, culture, science, market and user preferences. In this study, the focus is on the automation of road transport, not on other modes of transport. However, links to other modes exists to some degree as multimodality is expected to increase, e.g. due to MaaS (Mobility as a Service). Freight is discussed in some degree, but the focus is more on the transport of people, also for the impact estimates. Several parameters would be needed to provide a description of the system. In a scenario description, decisions will be made as to which parameters will be constant. Other factors will be varied less systematically or treated as dependent variables (safety, efficiency etc. – impact areas). It is acknowledged that there are complex interrelationships between variables and thereby complex impact mechanisms. Scenarios are simplified descriptions of reality and are made with the intention to highlight the possible consequences and impacts of selected alternative decisions.

Two recent scenario-based studies on automated driving and automation penetration ended up with quite similar key variables; both highlighted the role of road authorities and service development. Brenden & al (2017) discussed the factors of whether urban policy and planning would be ambitious and proactive or slow and careful, and whether shared solutions would make a breakthrough. Milakis & al (2017) had as main factors supportive vs. restrictive policy and high vs. low technological development. The POLIS (2018) discussion paper on road vehicle automation from the perspective of cities and regions stresses the more prominent role of local road authorities and public transport providers in policy around automation in road transport. The paper presents potential directions of automated transport but also the measures and policies of road authorities.

Technologies enabling automated driving and travelling services can be seen as (niche) innovations (emerging from novelties supported by networks). Regarding the technologies, the development paths as described by ERTRAC (2017) and CARTRE D5.1 (2017) created a starting point. More recently, CARTRE D5.2 (2018) on future research needs was published. Three development paths indicate which automated driving services are expected to be available for the selected target years: the passenger car, the freight vehicle and the urban mobility vehicles path.

The sociotechnical landscape “forms an exogenous environment beyond the direct influence of niche and regime actors (macro-economics, deep cultural patterns, macro-political developments). Changes at the landscape level usually take place slowly (decades)” (Geels and Shot 2007, p. 400). Developments in the socio-technical landscape create pressure and opportunities for the current regime to evolve into a new system. In the analyses, the most critical perspectives in the landscape are on the one hand climate change, and the need to reduce greenhouse gas emissions influences transport policies at all levels of society. The direct toxicity of fine particles and soot is gaining awareness quickly (WHO 2018). On the other hand, the economy, specifically the employment of people and digitalization, was seen as a remarkable change taking place in this period.

The Trilateral Working Group on Automation in Road Transportation (Trilateral ART WG) has suggested a framework to analyse the impacts of automated vehicles (Innamaa et al. 2018). The aim has been to increase international coordination and harmonization to maximize the insight obtained and to enhance complementary evaluation across the world. Trilateral ART WG published a framework for assessing the impacts of automated driving (Innamaa et al. 2018, based partially on Smith et al. 2015). It included impact classification of nine impact areas (Figure 2) and impact mechanisms. Furthermore, the group worked to create recommendations of the KPIs for expressing the impact of automation in road

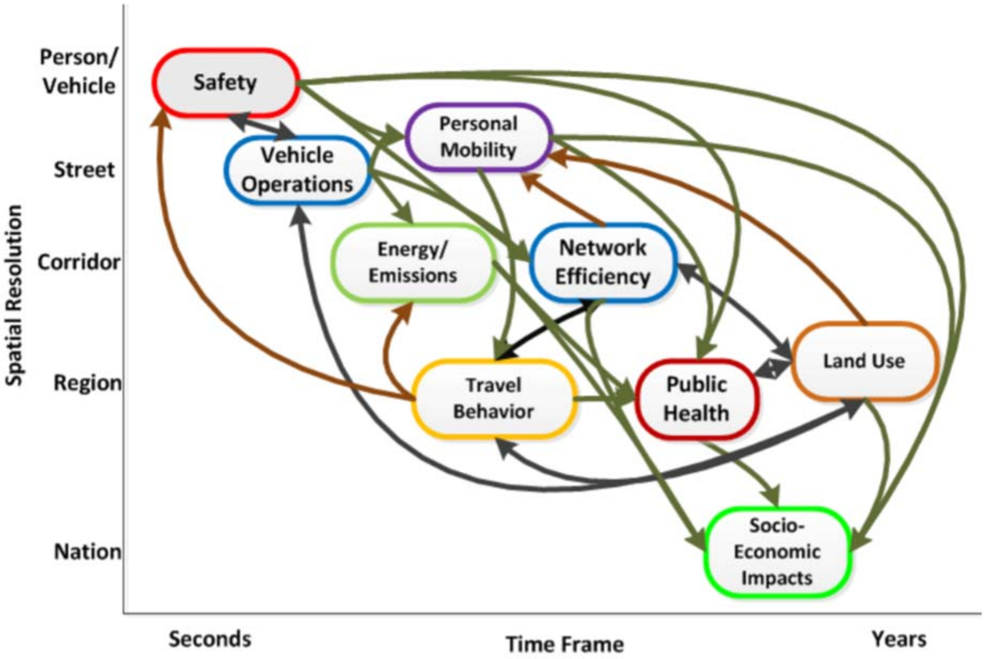


Figure 2. Impact Areas (Smith 2016).

transportation (Innamaa & Kuisma 2018). The framework suggested by the Trilateral ART WG was utilized in the societal impacts of automation in this study.

This work addresses two objectives. The first outlines an estimation of the societal impacts of automated driving at European level (EU28). The estimation was formed based on a qualitative expert assessment among CARTRE partners. The assessment was done for alternative scenarios and for a group of automation services. Due to its extensive scope, the estimation produced was qualitative and aimed rather to indicate the possible impacts of automated driving in different future scenarios, and to give rise to discussion, rather than predicting the future. The second objective was to compile an overview of the impact assessment plans and public results from ongoing automation pilot projects. This second part was carried out in cooperation with the CARTRE WP4 and task 2.4.

3. Method for estimation of societal impacts of automation

3.1. General approach

Estimates of the societal impacts of automation were produced by conducting a scenario-based impact assessment. Four scenarios were described to create context for the assessment (see next chapter). In the evaluation process, experts involved in the project task gave their insights on the impacts of automated driving in each scenario.

Impact areas addressed were based on the work by the Trilateral ART WG. Altogether eight impact areas were evaluated:

1) Use and acceptance of automated driving
2) Driver behaviour
3) Mobility and travel behaviour
4) Network efficiency
5) Energy and environment
6) Public health and safety
7) Land use (incl. parking space)
8) Economic analysis

The eight impact areas were divided into three groups for the evaluation process. Further, they were roughly classified as first- and second-level areas based on how direct the impacts were assumed to be. The impact areas interact with each other in various and complex ways. Therefore, we chose scenario-based assessment to handle these dependencies at least to some degree, but acknowledge that there are many scenarios not covered in this assessment. Indirect impacts were considered for most impact areas but no specific procedure was designated to assess them systematically.

The evaluation work was done by three groups of experts. The groups' first task was to sketch impacts and impact mechanisms within each impact area to create an overall picture of the possible socio-economic impacts of automated driving. Next, a suitable list of KPIs for each impact area was discussed. The KPIs by Trilateral ART WG were used as a starting point for selection. Not all of these were, however, addressed and some new KPIs were added. For five impact areas (use and acceptance, mobility and travel behaviour, public health and safety, land use and economic analysis) it was discussed what would be the beneficial/targeted direction of change in each KPI from a societal perspective. The results were later presented in relation to societal benefits.

The experts evaluated the impacts based on their experience. They shared their insight on the direction of change (increase/no change/decrease) and magnitude of change (on a scale of 1–5 where 1=small change and 5=large change) regarding KPIs for all four scenarios. For three impact areas (driver behaviour, energy and environment and network efficiency), it was found necessary to evaluate the impacts for a group of automation services (service-based estimation) before assessing the impacts in scenarios (service-based estimation) (see chapter 3.2). Values were relative in nature enabling comparison of estimated impacts between the scenarios rather than giving estimates of percent or absolute changes.

After giving their estimates, the experts were instructed to discuss them in groups. The purpose was to identify the reasons, if any, behind differing opinions on impacts and to see whether a consensus on the impacts for each KPI could be reached within the group. In addition, the experts were asked to write down descriptions of the factors influencing the effects and other reasoning behind their estimates.

A summary of the work done in three groups and the differences in working processes is illustrated in Figure 3.

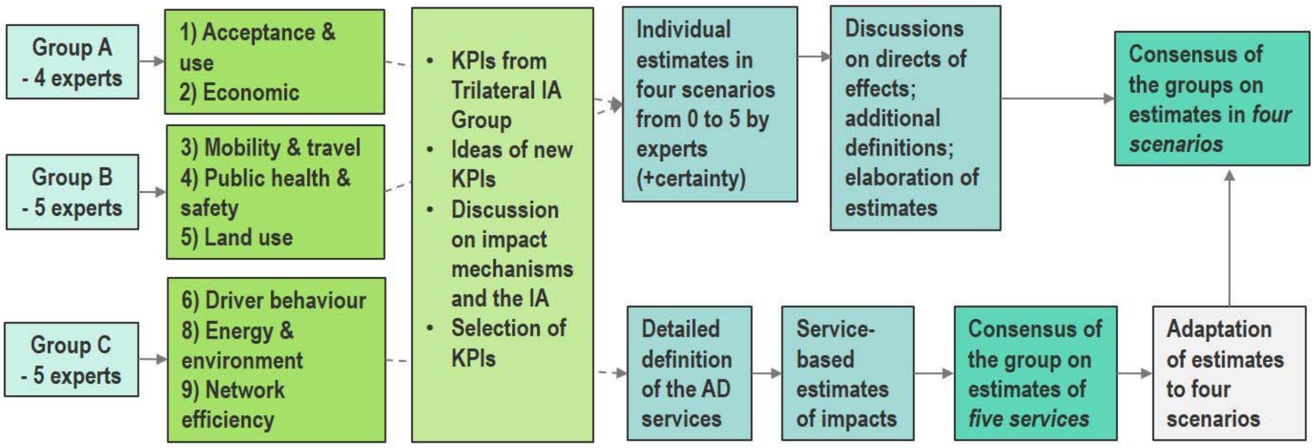


Figure 3. Workflow of work done in expert groups.

As a part of this work, also a breakout session on socio-economic impacts of automated driving was held in EUCAD2018 symposium in Vienna. In the session, three speakers gave their insights regarding specific aspects related to socio-economic impacts of automated driving. After every speaker presentation, there was an interactive session where the focus was on engaging the audience to share their views on impacts related to the speaker's topic. In the interactive session, the audience estimated selected impacts in three long-term scenarios (Chapter 5.3). Full report of the breakout session is in Appendix 4.

3.2. Detailed AD service-based estimation

In the analysis of three impact areas (driver behaviour, energy and environment and network efficiency), a more detailed description of automated driving (AD) services was found to be necessary. The estimates were, in the first phase, made service-based and the five services were the following (see Appendix 1 for more detailed descriptions of the services):

1. Highway autopilot including highway convoy
2. Urban & suburban pilot
3. Automated valet parking
4. Privately operated, automated personal rapid transit (PRT)/shuttles in mixed traffic
5. Publicly operated, automated buses and trams in mixed traffic.

It is worth noting that the services do not cover rural roads, which substantially affected the magnitude of estimates. Moreover, as part of the analysis, more detailed calculations of system penetrations of the services were made. In these calculations, the assumed vehicle penetration of a specific application (e.g. highway autopilot) was taken as a starting point and was multiplied by factors such as 'share of vehicle kms driven by target vehicle population in operational design domain (ODD) and usage of the AD function (Table 1). The results of the ecoDriver project (2011–2016) were utilized in the estimates of vehicle kms in different road types. The calculations resulted in quite small system penetrations. In addition, AD services for freight were not covered in this part.

For these three impact areas, a scale from 1 to 5 was defined as numerical estimates (see Appendix 2).

Table 1. Calculations for the service-based assessment in driver behaviour, energy and environment and network efficiency impact areas.

Deployment / system penetration in ~2035									
Application	Targeted vehicle type (vehicle population)	A = % of targeted vehicles AD equipped	Definition ODD	% vehicle kms represented by targeted ODD	% vehicle kms driven by target vehicle population in ODD	% vehicle kms of targeted ODD which can be used by target population (free of system limitations/ constraints)	% usage within ODD where there are no limitations for target population	% of all vehicle kms driven by AD equipped vehicles where system can be used and is used	% of all vehicle kms driven by AD equipped vehicles where system can be used and is used, limited to the ODD
Label		A		B	C	D	E	F	G
Calculation						Assumption		A x B x C x D x E	A x C x D x E
Highway Autopilot /cars	All cars	50%	Motorway - Interurban and urban	16.9%	79.3%	80%	80%	4.29%	25%
Urban & Suburban Pilot (USP)	All cars	25%	Urban Spacious	13.9%	86.4%	80%	20%	0.48%	3%
Automated Valet Parking (AVP)	All cars	60%	Parking lots (not represented in the veh-kms)	0.0%	0.0%	80%	90%	0.00%	0%
Highly Automated Vehicles on Dedicated Lanes/roads/areas			Not analysed						
(Organized) Highway pilot Truck Platooning			Not analysed						
Private operated, Automated Personal Rapid Transit (PRT)/Shuttles in Mixed Traffic	All taxis/commercial ridesharing services (e.g. Über)	40 %	Urban - compact and spacious	27.8%	4.3%	80 %	100 %	0.38 %	1 %
Public operated, Automated buses (and trams) in Mixed Traffic	PT buses	40 %	Urban - compact and spacious	27.8%	1.5%	80 %	100 %	0.13 %	0 %

4. Selection of KPIs per impact area

This chapter introduces KPIs for the selected eight impact areas. Each indicator is described and given a targeted direction of change. The targeted direction is the one with likely beneficial societal impacts.

4.1. Driver behaviour

For driver behaviour, the following 8 KPIs were selected:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Maximum speed v95	The 95th percentile speed (km/h)	NA
Average speed	Km/h	Increase for network efficiency & mobility, decrease for safety
Eco-driving	Degree of how the actual driving style (of the fleet) accords with the optimal driving style on the perspective of energy-efficiency	Increase
Unnecessary decelerations/low speed due to VRU	Number of unnecessary decelerations due to VRU	Decrease
Time headway	Time between vehicles (seconds)	Can be both
Post encroachment time (PET)	The time between the moment that the first road-user leaves the path of the second and the moment that the second reaches the path of the first (seconds)	Decrease for efficiency & mobility with threshold for safety (and comfort)
Adaptability to traffic conditions	Degree on how the driving behaviour is adapted to the traffic conditions (subjective)	Increase
Reaction time	The time it takes to respond to a stimulus (seconds)	Decrease

4.2. Mobility & travel behaviour

For mobility and travel behaviour, the following KPIs were selected:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Number of trips	Number of trips/day/person	Increase (transport system to enable mobility)/decrease (decreasing disadvantages of travelling)
Total travel time	Minutes/day/person	Decrease/increase (faster travel is targeted to enable mobility of people)
Total kilometres travelled	Travel kilometres for a region or population	Increase (transport system to enable mobility)/decrease (decreasing disadvantages of travelling)

Share of each transport mode (car)	Share of kms travelled by car (%)	Decrease
Share of each transport mode (public transport)	Share of kms travelled by public transport (%)	Increase (shift from private car usage)
Share of each transport mode (bicycle)	Share of kms travelled by bicycle (%)	Increase
Travelling at peak hours (timing)	Share (%) of trips made during peak hours	Decrease
Travelling reliability	Subjective (Likert scale, e.g. 1–5) or e.g. share of trips completed without delays or below threshold of delay	Increase
Travelling comfort	Subjective (Likert scale, e.g. 1–5)	Increase
Accessibility of lower density areas	Quality of low-density area to be reached (low–high) or number of opportunities or activity sites available for people living in low-density area within a particular travel time or distance. Low-density area needs to be defined (population/km^2)	Increase

4.3. Network efficiency

The list of selected KPIs for network efficiency is as follows:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Road capacity	Vehicles/hour	Increase
Total or average travel time per road-km	Minutes/road-km	Decrease
Intersection capacity	Vehicles/hour	Increase

4.4. Energy and environment

For energy and environment, two KPIs were selected:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Energy savings due to reduced air resistance	Percentage of saved energy [kWh] compared to traction energy used without automation (% [kWh/kWh])	Increase
Energy use for in-car IT technology	Percentage of additional energy [kWh] compared to traction energy used today (% [kWh/kWh])	Decrease (additional energy use is negative)

In addition, an eco-driving KPI (degree of how the actual driving style (of the fleet) accords with the optimal driving style on the perspective of energy efficiency) is being included in the driving behaviour impact area, but it is relevant for energy and environment as well.

4.5.Public health and safety

The list of selected KPIs for public health is as follows:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Total mileage travelled by active modes of transportation (walking and bicycle)	Kms	Increase
Proportion of people with improved access to health services	Percentage of total people in a region who have obtained improved access. The definition of improvement is important. It must be e.g. a reduction of 20% or more on travel time.	Increase
Improved access to recreation and other services	Number of visits to each type of service/ year	Increase
Social isolation	Lack of potential for interactions with other people (subjective or decrease in number of potential interactions)	Decrease
Number of injuries	Number of injuries in road transport/year/ million inhabitants	Decrease
Number of fatalities	Number of fatalities in road transport/year/ million inhabitants	Decrease

4.6. Land use

The list of selected KPIs for land use is as follows:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Underground parking space in city centre areas	Space needed for underground parking (m^2)	Decrease
Street parking space in city centre areas	Space needed for street parking in city centre areas (m^2)	Decrease
Location of employment (distance from city centre)	Distance of employment from city centre (kms on average)	Decrease in commuting kms
Number of lanes	Number of lanes needed	Decrease/increase if less space per lane

4.7. Use & acceptance

User acceptance can guide the adoption or rejection of systems and must therefore be examined in detail to understand what is acceptable and what is not, and for what kind of reasons. For use and acceptance, in all over 20 KPIs were discussed. The following 10 KPIs were addressed in the final evaluation:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective

Use of automated driving functions	Share of kms driven within the ODD when the driver decides to use automation	Increase
Requirement of attention and concentration (for driving)	Whether the driver has to be attentive to driving or not, and to what extent (varies with SAE level).	Decrease
General feeling/acceptance of general public	The public considers that AD is reliable, safe, useful and might be used for the purpose it is intended to.	Increase
Trust (Connected and Automated Driving, CAD, users)	Experienced trust (Likert scale: e.g. I do not agree at all – I fully agree in 5 steps)	Increase
Perception of reliability	Experienced reliability (Likert scale)	Increase
Perceived usefulness	Experienced usefulness (Likert scale)	Increase
Perceived comfort	Experienced reliability (Likert scale)	Increase
Feeling of safety (from the perspective of vehicle users)	Subjective safety (Likert scale)	Increase
Feeling of control of the overall situation (from the perspective of vehicle users)	a) Feeling of being able to control the vehicle at any time b) Feeling of control over the vehicle while the system is driving (Likert scale or share of time when feeling able to have control)	a) Increase b) Decrease due to delegation of responsibility to AV
Intended use	Will the drivers think they would use the AD systems more and more often?	Increase

The list above focuses on the use and acceptance of AD users. Furthermore, user acceptance can be regarded also from the point of view of road users without automated support, i.e. how automation affects their feeling of safety or comfort.

4.8. Economic analysis

For the economic analysis, in all over 20 KPIs were discussed and evaluated. The KPIs are presented in two separate tables; the first indicates the measures for growth and productivity. These can be seen as benefits in a socio-economic calculation (above the line):

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective
Growth of automotive industry (manufacturing)	Growth of annual turnover	Increase
Growth of transport services sector	Growth	Increase
New established businesses	Number of newly established business	Increase
Total factor productivity/multi-factor productivity estimates	Productivity of mobility services	Increase

The second table relevant for the economic analysis addresses cost and investment related KPIs:

Name of KPI	Definition of KPI (unit)	Targeted direction of change from societal perspective (reference: transport costs today to the public)
Capital cost per CAD vehicle	Cost	Decrease
Operating cost for deployed system	Cost	Decrease
Cost of purchased automated vehicle	Sales cost	Decrease for mobility operator (increase for carmaker)
Investment cost for digital infrastructure and connectivity network	Cost	Decrease
Operation and maintenance cost for digital infrastructure and connectivity network	Cost	Decrease
Investment cost for physical infrastructure	Cost	Decrease
Operation and maintenance cost for physical infrastructure	Cost	Decrease
Cost per trip for user	Cost	Decrease

Examples of KPIs for which it was hard to find a consensus about impacts are:

- Number of jobs in the transport sector (operational)
- Cost of education per driver

5. Assessment scenarios

5.1. Selected scenarios

According to the goal – provide impact estimates for different automation scenarios in road transport – we determined four alternative scenarios. Scenarios are plausible descriptions of the future; they can be seen as stories of what could happen and what it would look like. We considered Europe for our assessment.

In the analysis, our intention was to cover one short-term and three long-term scenarios. It was assumed that no radical changes would occur in the short term and the future paths would differentiate from in other more in the long term – which is an interesting base for assessment. Due to the high level of uncertainty attached to AD development, we did not provide exact years. The short-term scenario refers to the near future (not 'tomorrow'), up to around 2025. The long-term scenario is still fairly close timewise – somewhere just beyond 2030, as current technology paths do not go much further.

The four scenarios are described in the following chapters 5.3 and 5.3. A summary of scenarios and their main differences is illustrated in Table 2. The same automated vehicle technologies and their maturity is assumed in all the long-term scenarios. In addition to the time aspect and maturity of technology, the development of shared mobility services, the availability of public transportation and the locus of control (role of public authorities) were identified as three main differentiating factors between the scenarios (Brenden & al 2017, Milakis & al 2017, POLIS 2018).

Table 2. Summary of the assessment scenarios.

	SHORT-TERM SCENARIO (~2025)	LONG-TERM SCENARIOS (~2035)		
	Scenario 1 *Gradual extrapolation of automated services*	**Scenario 2** *Market-operated fleets of shared automated vehicles*	**Scenario 3** *Authority-driven shared automated transportation*	**Scenario 4** *Proliferation of private automated vehicles*
Automated vehicle technology	Gradual introduction of automated functions	Mature SAE L4 automated vehicles, penetration >50% in mixed traffic		
Use of shared mobility services	High interest, early adaptors use	High	High	Low
Locus of control	Cautious but enthusiastic public support for automated vehicles & mobility services	Private	Authority-driven, public-private collaboration	Private

5.2. Short-term scenario (~2025)

SCENARIO 1: Gradual extrapolation of automated services

Automated vehicles technologies

Following the gradual launch of new automated functions, new cars have at least optional SAE L2 automation functions such as traffic jam assist, lane keeping assist and parking assist in addition to the SAE L1 ACC Stop & Go assist. For freight vehicles, cooperative-ACC truck platooning is commonplace. SAE L2 AD functions for cars and SAE L3 functions for trucks were launched some time ago and are now widespread. Overall, there are more SAE L3 functions for freight than for cars: traffic jam chauffeur and highway chauffeur are expected to be in general use in trucks already in the short term (ERTRAC 2017, CARTRE D5.1 2017).

For cars, SAE L3 level functions have been introduced including traffic jam chauffeur, highway chauffeur and automated urban bus chauffeur (ERTRAC 2017, CARTRE D5.1 2017), but the system penetration is quite low (less than 20% at a rough estimate). In urban transport, bus assist (L2) and bus chauffeur (L3) have been launched and there are SAE L4 buses and shuttles on dedicated roads.

It is assumed in this scenario that new cars are equipped with cooperative systems to enable connectivity of vehicles and C-ITS. This means that more information about surrounding circumstances, incidents and traffic are conveyed to the drivers; introduction of eCall and C-ACC truck platooning (providing information on traffic downstream) are examples. However, as system penetrations are still small, automated functions cannot be built on the assumption of connectivity. In addition, we assume that the impacts of informative C-ITS services (Malone & al 2014) are smaller than those of interfering functionalities.

It is assumed in this scenario that user interfaces have been developed in pilots and field tests. Users are quite aware of the function properties, and the functions implemented are fairly widespread.

Development of shared mobility services and public transportation

There is a high level of interest in shared mobility services among road authorities and private companies. New kinds of mobility services (e.g. private MaaS packages, car or ride sharing) keep on emerging especially in urban areas, and early adaptors are willing to try them. On a large scale, these are growing but still quite marginal. In some cities, and in some urban areas (not yet widely in Europe), automated buses are operating on dedicated roads or areas. Organizing public transport is largely based on traditional mass transportation (metros, trams, buses). Multimodality of public transport is promoted. Some new services offer travel packages combining private car share service and public transportation, and also active modes like cycling. Some private services are more focused on car sharing only.

Policies and the role of transport authorities

In this scenario, the public sector has been supportive towards the development of automated vehicles and testing, as well as new mobility services, because of their potential to encourage economic growth, promote well-being and contribute to reaching goals related to the reduction of emissions. The public sector contributes in that the new privately-operated mobility services would end up complementing public transport, cycling and walking, and would attract people away from owning and using private cars. Transport authorities are mostly open to cooperation with private actors. Public authorities are being cautious, since the impacts of new technologies and innovations are still unclear. So far, the role of transport authorities has been reactive rather than introducing shared and automated mobility as part of an integrated planning process. The forerunner cities implementing automated services are followed closely. Public transportation is continuously being developed, and new services and business models are emerging alongside the technology development of automated systems. The EC (and global organizations) is implementing regulation to enable and support implementation of C-ITS and automation.

5.3. Long-term scenarios (~2035)

Automated vehicles technologies in long-term scenarios

Future AD technologies are going to be built on the existing partial automation and related experience. In long-term SAE L4, functions in use include highway autopilot, urban and suburban pilot, and automated shuttles and buses in mixed traffic. The freight vehicles path includes SAE L4 HAVs (highly automated vehicles) on dedicated and open roads and highway pilot platooning. It is also assumed that light goods vehicles (vans) for deliveries and services have automated L4 functionalities.

Still, as renewal of cars is quite slow in many European countries, the vehicle penetration is not very high; it may be over 50% but seldom close to 90%. The occurrence of automation differs, however, depending on the area, ODD of functions, willingness to use, etc. SAE L4 functions are assumed to be more mature and more in use on highways (and parking) than in urban mixed traffic. The bundled functionality of automated cars such as a combination of highway autopilot (including highway convoy), urban and suburban pilot and L4 automated parking function (parking while outside the car) are enabling some drivers to be free of the driving task a considerable part of the time. In addition, shared ownership and high technology solutions for cars may speed up the rate of renewal.

SCENARIO 2: Disruption through market-driven services

Development of shared mobility services and public transportation

Shared mobility services have broken through and become mainstream. Shared mobility services are reliable and convenient in most cases. Fleets of shared and automated vehicles are market operated. Operators are competing against each other for customers, and different levels of service are available. Premium subscribers gain access to better and faster services than basic subscribers. These privately-operated fleets of vehicles have partly replaced traditional public transportation, especially on short distance trips and in densely populated areas.

Shared mobility is mainly based on the provision of cars. Services are not really multimodal, they are not well integrated with the public transportation service, and connection to and cooperation with mass transport is not well planned. As cooperation is insufficient, travel chains do not cover all modes well. Travel packages based on other modes than cars have not been successful on the market.

Public transportation is continuously being developed, new services and business models are emerging in parallel with the technology development of automated systems. An increase of driverless buses is reducing the costs of bus travel. The rail system is maintained for the major origin and destination locations.

Policies and the role of transport authorities

Transport authorities direct market-operated transportation through regulations and subsidies that clarify responsibility issues and encourage private operators towards lower emissions and intelligent use of urban space. Since market-operated fleets of shared and automated vehicles have mostly replaced traditional public transportation, road authorities aim to promote social equity by regulations and subsidies to ensure a minimum level of mobility services to all people.

SCENARIO 3: Authority driven with focus on collective transport

Development of shared mobility services and public transportation

In this scenario, there is a system of driverless vehicles providing demand-responsive public transportation for selected routes. There has been a proliferation of commercially explored automated public transportation systems (e.g. pods). The main private operators of public transportation have invested in creating these systems, which have been subsidized by the public sector. Road authorities retain strategic control of the network. The main use of the systems is for access and egress of major public transport hubs and for lower-density areas. Most of the people have accepted and been used to sharing their trips and car. Travel chains are well functioning and intermodal.

Policies and the role of transport authorities

Shared and automated mobility is part of the integrated planning process, which is based on public-private collaboration. Public authorities remain proactive and road authorities retain strategic control of the transport network. Privately owned automated vehicles are being quite heavily taxed both centrally and locally through road price charging and parking, for example. Physical and digital infrastructure has been built in (part of) the strategic network.

SCENARIO 4: Privately operated fleets with authorities focusing on constraints and safety only

Development of shared mobility services and public transportation

People do not respond well to sharing automated vehicles with strangers without a driver present. Thus, sharing remains marginal: not many systems have broken the barrier to being commercially explored by private companies, and public companies are not adopting them. Owning automated vehicles is affordable for most people.

Policies and the role of transport authorities

Governments have not been able to get public acceptance of increasing restrictions to private automated vehicles. Policies focus on reducing emissions, managing urban space effectively, and increasing the safety of automated vehicles.

6. Effects of AD in each impact area

6.1. Factors identified to increase/decrease the effects

For this chapter we listed factors which were identified in the group discussions as increasing or decreasing the effects of AD. The content is organized by KPIs selected for the assessment. There may be variations in the level of detail, because responsibility for the impact areas was assigned to three groups.

Use & acceptance

Use of AD functions

- System performance and its reliability
- Knowledge on safety impacts and experienced safety
- Trust in the automated system
- Positive representation, etc.

Requirement of attention and concentration (for driving)

- Increasing automation, e.g. according to SAE levels
- Reliability of systems
- Perception or reliability
- Perception of safety

General feeling/acceptance of the general public

- Reliability of systems
- Perception of reliability
- Perception of safety
- Trust in automated functionalities
- Understandability
- Number of negative experiences, e.g. crashes
- Trust in car makers
- Consumer test
- Clarity of regulations
- Support by public authorities

Trust (for CAD users)

- Reliability
- Number of negative experiences, e.g. near-crashes or crashes
- Comprehensibility
- Usefulness

Perception of reliability

- Real-world reliability
- Point of reference (personal experiences)

Perceived usefulness

- Real-world usefulness
- Point of reference (personal experiences)

Perceived comfort

- Performance and reliability
- Positive experience of human-to-machine transitions
- Clear feedback from the system
- Perception of good driving by the system
- Understandability/traceability of system behaviour/actions

Feeling of safety (from the perspective of vehicle users)

- Performance and reliability
- Good experience of transitions
- Good feedback from the system
- Perception of good driving by the system

Feeling of control over the overall situation (from the perspective of the vehicle user)

- Performance and reliability
- Good experience of transitions
- Good feedback from the system
- Perception of good driving by the system

Intended use

- Usefulness
- Reliability
- Performance

Driver behaviour

Maximum speed v95

- Penetration rate of automated vehicles
- Traffic composition in terms of shares of vehicles of different SAE levels
- Defensive/conservative CAD driving styles (will lower maximum speeds)
- Proportion of trucks on the roads (lower-speed already now)
- Spare capacities

Average speed

- Penetration rate of automated vehicles
- Traffic composition in terms of shares of vehicles of different SAE levels
- Defensive/conservative CAD driving styles (will lower speeds)
- Proportion of trucks on the roads (lower-speed already now)
- Spare capacities

Eco-Driving

- Penetration rate of automated vehicles
- Traffic composition in terms of shares of vehicles of different SAE levels
- Proportion of trucks on the roads (lower-speed already now)
- CAD software settings (including what is acceptable to CAD occupants)
- Level of connected-vehicle functionality/technological maturity (better at estimating overall traffic)

Unnecessary decelerations/low speed due to VRU

- Specifics of the ODD – in which contexts the AVs are active/functioning
- Very much depending on how well CAD/humans will understand each other
- How VRUs “learn” to push the limits of CAD (stepping out, knowing it will stop etc.).

- CAD sensor/identification/tracking/decision algorithm performance

Time headway (THW)

- Legal and policy requirements for CAD THW settings
- CAD settings and ability for the driver to customize THW settings
- Country (specifically with respect to the propensity of THW manual driver cut-ins)
- The availability of a CAD option to automatically adjust settings to avoid constantly being overtaking (again, will be affected by country)
- Proportion of trucks on the road (slower-moving)

Post encroachment time (PET)

- Specifics of the ODD – at which intersections the AVs are active/functioning
- Legal and policy requirements for CAD PET settings
- Trust in the systems (both in CAD and other vehicles)
- How conservative are the CAD settings for PET are (e.g. OEM and culture dependent)
- Level of connected-vehicle functionality (better at estimating intent and state of other road users)

Adaptability to traffic conditions

- Complexity of traffic (will strongly depend on application)
- Region tyre (urban, rural, etc.)
- How well CAD can predict humans (based on sensors, tracking, prediction etc.)
- CAD technical performance (how well it can identify/track/predict road users and infrastructure)
- Level of connected-vehicle functionality (better at estimating overall traffic)

Reaction time

- Complexity of traffic (will strongly depend on application)
- How well CAD can predict humans (based on sensors, tracking, prediction etc.)
- CAD technical performance (how well it can identify/track/predict road users and infrastructure)
- Level of connected-vehicle functionality (better at estimating overall traffic)

Mobility & travel behaviour

Number of trips

- Ease of travel & travelling comfort
- Location of residence, employment, services
- Ownership of transport vehicles, access to transport services
- Situation in life, personal needs and activity
- Personal income
- Health and coping, physical abilities and mental resources
- Routines

Total travel time

- Number of trips
- Length of trips
- Mode choice
- Transport system design
- Route choice
- Timing of trips (congestion)

- Shared mobility

Total kilometres travelled
- Number of trips
- Length of trips
- Mode choice
- Route choice
- Shared mobility

Share of each transport mode (car)
- Private car ownership, driving licence and skills
- Availability of car sharing/car-based shared mobility services
- Availability of other transport modes
- Costs of driving and personal income
- Place of residence
- Travelling comfort by (private) car, compared to alternatives
- Personal preferences and lifestyle, identity, status
- Enjoyment/stress of driving
- Situation in life (family, health, etc.)
- Availability of parking
- Congestion

Share of each transport mode (public transport)
- Availability (& service level & cost) of public transport
- Private car ownership
- Availability of car sharing/car-based shared mobility services
- Costs of car and personal income
- Place of residence
- Travelling comfort by public transport
- Personal preferences and lifestyle
- Situation in life (family, health, etc.)
- Availability of parking

Share of each transport mode (bicycle)
- Ownership of vehicles, access to other modes of transportation
- Place of residence, including physical environment and climate
- Personal preferences and lifestyle
- Situation in life (family, health, etc.)
- Private car ownership
- Costs of car and personal income
- Bicycle lanes and traffic design
- Availability of bicycle parking and storage

Travelling at peak hours (timing)
- Flexibility of working hours
- Value of time
- Value of travel time (possibility to focus on (other than driving) activities while travelling)
- Hours of congestion

Travelling reliability

- Reliability of mobility services and public transport
- Congestion
- Road works, crashes

Travelling comfort
- Ease of travel, effort required
- Changes from one vehicle to another
- Reliability of travelling
- Privacy/other passengers
- Possibility to focus on (other than driving) activities while travelling, entertainment
- Smoothness of driving, motion sickness
- Comfort of seats
- Perceived safety

Accessibility of lower density areas
- Ownership of private cars, costs of driving, driving licence & ability
- Availability and service level (and costs) of public transport, subsidies for public transport
- Availability of market-based mobility services

Network efficiency

Road capacity
- Mixed traffic (different SAE levels). As the percentage of AVs in the traffic stream increases, road capacity may decrease. This is due to the discontinuities such as entrances and exits, weaving sections and lane drops, where lane changing needs to take place. Only at high penetration rates can communication between vehicles be used to create suitable gaps, which may allow the road capacity to increase
- Higher percentage of trucks in the traffic stream → most likely decreases road capacity
- Time headways → increased time headways decrease road capacity
- More homogeneous speeds of drivers (smaller standard deviation of vehicle speeds) → fewer shockwaves, hard braking, etc. lead to increased road capacity; on the other hand, lane changing becomes more difficult (decreased road capacity), unless the majority of vehicles can communicate so that suitable gaps can be created

Total or average travel time per road-km
- Average speed → increase in average speed reduces travel time
- Road or intersection capacity decreases → travel time increases

Intersection capacity
- Distinction between signalized and unsignalized intersections
- Signalized intersections: if the intersections are chaotic (traffic rules are not observed), then the AVs probably cannot perform as well as human drivers
- Signalized intersections: shorter reaction times to cycle changes and synchronized acceleration can increase capacity
- Unsignalized intersections: minimize the number of conflicting streams in order not to decrease capacity
- Higher percentage of trucks in the traffic stream → most likely decreases intersection capacity

Energy and environment

Energy savings due to reduced air resistance

- In this KPI, only energy savings due to wind shadow have been considered. Note: air resistance increases as the cube of the velocity. To assess the overall energy consumption, the KPI “speed” and the KPI “Eco-driving” (KPI included in driver behaviour impact area) must be considered also
- Energy savings due to reduced air resistance are only relevant at higher speed levels (highway pilot) but not at low speeds (parking pilot). Besides speed, the distance between vehicles affects this KPI (convoys, platoons). Very short distances can only be realized with V2V communication. The application with the most relevant effect for this KPI (i.e. truck platooning) has not been assessed. High Automation also allows unmanned transport and thus new logistics concepts. Freight transport at low speed during the night might significantly cut energy use. Since freight transport is not included in the scenarios, this effect has not been assessed

Energy use for in-car IT technology

- Automated vehicles need a huge number of sensors, cameras and other devices with tremendous computing power. All such devices need electric energy, thus increasing the use of energy. The number of devices and their energy efficiency influence this KPI

Public health and safety

Total mileage travelled by active modes of transportation (walking and bicycle)

- More sharing should lead to more usage of soft modes. More private usage of automated vehicles could mean that private vehicles are even more attractive, thus forming a lower share of soft (active) modes

Proportion of people with improved access to health services

- The more people who have access to mobility services, the more have access to health services. Lower levels of automation will not make much difference to this indicator. The automation has to be Level 4 or 5. Level 5 will have the strongest effects

Improved access to recreation and other services

- Lower levels of automation will not make much difference to this indicator. The automation has to be Level 4 or 5. Level 5 will have the strongest effects

Social isolation

- Lower levels of automation will not make much difference to this indicator. The automation has to be Level 4 or 5. Level 5 will have the highest effects

Number of injuries

- Each automation level can help improve this number by contributing to a decrease in human error

Number of fatalities

- Each automation level can help improve this number by contributing to a decrease in human error

Land use

Underground parking space in city centre areas

- Use of private cars in city centre areas
- Car sharing/shared mobility
- Features and functionality of automated vehicles in parking
- Urban policy

Street parking space in city centre areas

- Use of private cars in city centre areas
- Car sharing/shared mobility
- Features and functionality of automated vehicles in parking
- Urban policy

Location of employment (distance from city centre)

- Use of AD in commuting
- Willingness of employees to commute longer trips

Number of lanes

- Provision of dedicated lanes for automated vehicles

Economic analysis

Growth of the automotive industry (manufacturing)

- Vehicle volumes produced and sold
- Content per car

Growth of the transport services sector

- Usage of public mobility services
- Usage of personal mobility services
- Car sharing or car pooling
- Incentives from authorities
- Public opinion & societal evolutions

New established businesses

- Market evolution
- Innovation strategies
- Public opinion & societal evolutions

Total factor productivity/multi-factor productivity estimates

- Usage time of assets
- Amortization of investments
- Operating costs

Capital cost per CAD vehicle

- Technology required
- Business plan
- Services

Operating cost for the deployed system

- Workforce
- Maintenance
- Fees and taxes

Cost of purchased automated vehicle

- Technology required
- Volume produced
- Export or import taxes
- Exchange rates
- Pricing power
- Commercial competition

Investment cost for digital infrastructure and connectivity network
- Technology
- Location
- Safety and security

Operation and maintenance cost for digital infrastructure and connectivity network
- Technology
- Pricing power of big data operators
- Pricing power of cloud computing operators

Investment cost for physical infrastructure
- Building size
- Technology
- Location & land use

Operation and maintenance cost for physical infrastructure
- Technology
- Pricing power of construction companies

Cost per trip for the user
- Usage time
- Subsidies
- Commercial competition

6.2. Scenario-based estimates of automated driving

A scenario-based assessment was specifically conducted for five impact areas. The results are presented in Tables 3–8. The reasoning and motivations for impact estimates follow by impact area.

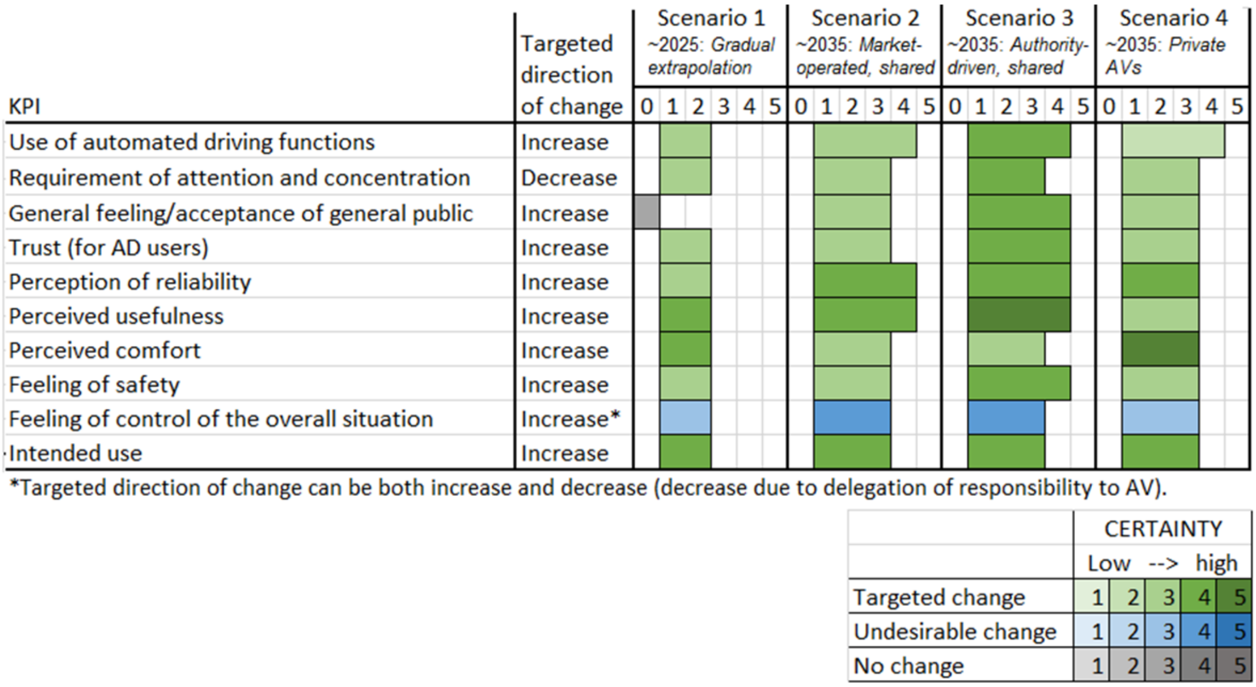
Reading of the Tables 3–8:
- The scale from 0 to 5 indicates the magnitude of change (0=no change, 5=large change) compared to the current situation.
- The colouring indicates whether the estimated impacts in each scenario are beneficial/targeted from a societal perspective or not (it was defined in Chapter 4 which would be the targeted direction of change for each KPI from a societal perspective). The impacts are marked in the tables as positive or negative (indicated by green and blue respectively). For example, if the targeted direction of change is an increase and the estimated change is an increase as well, this results in an estimated positive impact for the society.
- The darkness of the colouring indicates the certainty of the estimates: the darker the colour the more certain the estimate.

For assessment of three impact areas (driver behaviour, network efficiency and energy and environment), the experts found it more suitable to define more detailed AD service descriptions within which the estimates were given first (see chapter 6.3). Comparison of scenarios for these impact areas was described qualitatively and summed up in Tables 9–11. Due to small penetrations in the actual traffic flow, the differences of impacts between scenarios were minor.

Use & acceptance

Overall, the estimates of use and acceptance were positive from a societal point of view in all scenarios (Table 3).

Table 3. Estimated use and acceptance impacts for the society (scale: 0=no change, 5=large change).



As the most important factors influencing user acceptance, the group of experts highlighted the service provided by the AD system, the performance of the technology and whether the service is shared with others. Whether or not the service is public or private was assessed as having a lesser influence.

The most important differences between scenarios (regarding acceptance) were found between the short-term scenario (scenario 1) and the long-term scenarios (2, 3 and 4): user acceptance and use was assessed to be better in the long-term scenarios than in the short-term one. In general, the experts expected that AD would be well accepted and widely used by the public. There is only one KPI, “feeling of control of the overall situation” (from the perspective of the vehicle user), which appears negative. However, the direction is not that clear – a decrease in control can also be interpreted as a sign of more relaxed driving and trust in the system.

In addition to the differences related to the four scenarios, the group indicated that the different use cases, i.e. passenger car, public transport or freight, were considered when making the estimates. The following reasoning came up in the discussions:

- The interdependencies of KPIs: for example, a feeling of safety depends on trust and perception of reliability.
- The net effect resulting from potentially conflicting effects of each KPI and of potential varied effects depending on the use case: For example, the effect on comprehensibility might be negative due to the increase of information in the interface, whereas it could also be positive if a specific dedicated HMI is designed for AD use.
- Users can be divided into two major groups: users of passenger cars (drivers and passengers) and users of public transport (as passengers only).
- Acceptance is regarded not only from the viewpoint of users of AD systems or services, but also from the perspective of non-users and the public in general.

More detailed, KPI-specific motivations for use and acceptance estimates can be found in Appendix 3.

Mobility and travel behaviour

The estimated mobility and travel behaviour impacts of AD are presented below in Table 4 from a societal point of view.

Table 4. Estimated mobility and travel behaviour impacts for the society (scale: 0=no change, 5=large change).

KPI	Targeted direction of change	Scenario 1 ~2025: *Gradual extrapolation* (0 1 2 3 4 5)	Scenario 2 ~2035: *Market-operated, shared* (0 1 2 3 4 5)	Scenario 3 ~2035: *Authority-driven, shared* (0 1 2 3 4 5)	Scenario 4 ~2035: *Private AVs* (0 1 2 3 4 5)
Number of trips	Increase*				
Total travel time	Decrease*				
Total kilometres travelled	Increase*				
Share of car	Decrease				
Share of public transport	Increase				
Share of bicycle	Increase		NO ESTIMATE		
Travelling at peak hours (timing)	Decrease		NO ESTIMATE		
Travelling reliability	Increase				NO ESTIMATE
Travelling comfort	Increase				
Accessibility of lower density areas	Increase		NO ESTIMATE		

*Targeted direction of change can be both increase and decrease: decrease in travelling would decrease disadvantages of travelling (crashes, environmental impacts, costs…), but the aim of a transport system is to enable mobility.

	CERTAINTY				
	Low --> high				
Targeted change	1	2	3	4	5
Undesirable change	1	2	3	4	5
No change	1	2	3	4	5

It was estimated that the usage of different transport modes would change in different scenarios. In all long-term scenarios, it was assumed that the amount of travel would increase. This estimation is based on the assumption that travelling will become more comfortable along with new automated services. Especially the possibility to focus on other activities than driving while travelling was assumed to increase travelling. At the same time, it was estimated that total travel time would increase along with increased travel in scenarios 2 and 4.

Travelling reliability was assumed to increase in the short-term scenario and in long-term scenarios 2 and 3 (in which mobility is shared). In the case of scenario 4, there was no consensus concerning the travelling reliability estimate: on the one hand new automated services could increase reliability, but one the other congestion due to increased private car usage would weaken reliability. At the same time, a transport system based on private automated vehicles was seen as more comfortable than shared mobility systems.

In all, it seemed that not many changes would happen in mobility and travel behaviour in the short term. Some increase in travel comfort was assumed as well as some more travelling during peak hours due to AD. In the short term, usage of cars could increase as they became more attractive. When it comes to long-term impacts, it seemed clear that the most positive impacts were assumed in scenario 3 (automated public transport). The most negative impacts were estimated in scenario 4 (automated private cars), although some positive impacts were assumed in all of the scenarios. It emerged that impacts in scenario 2 (market operated shared mobility) was the most difficult one for experts to estimate.

Public health and safety

The estimated impacts of AD on public health and safety are presented below in Table 5 from a societal point of view.

Table 5. Estimated public health and safety impacts for the society (scale: 0=no change, 5=large change).

KPI	Targeted direction of change	Scenario 1 ~2025: *Gradual extrapolation* (0 1 2 3 4 5)	Scenario 2 ~2035: *Market-operated, shared* (0 1 2 3 4 5)	Scenario 3 ~2035: *Authority-driven, shared* (0 1 2 3 4 5)	Scenario 4 ~2035: *Private AVs* (0 1 2 3 4 5)
Use of active modes of transportation	Increase				
Number of injuries	Decrease				
Number of fatalities	Decrease				
Access to health services	Increase				
Access to recreation and other services	Increase				
Social isolation	Decrease	NO ESTIMATE	NO ESTIMATE	NO ESTIMATE	NO ESTIMATE

	CERTAINTY Low --> high				
Targeted change	1	2	3	4	5
Undesirable change	1	2	3	4	5
No change	1	2	3	4	5

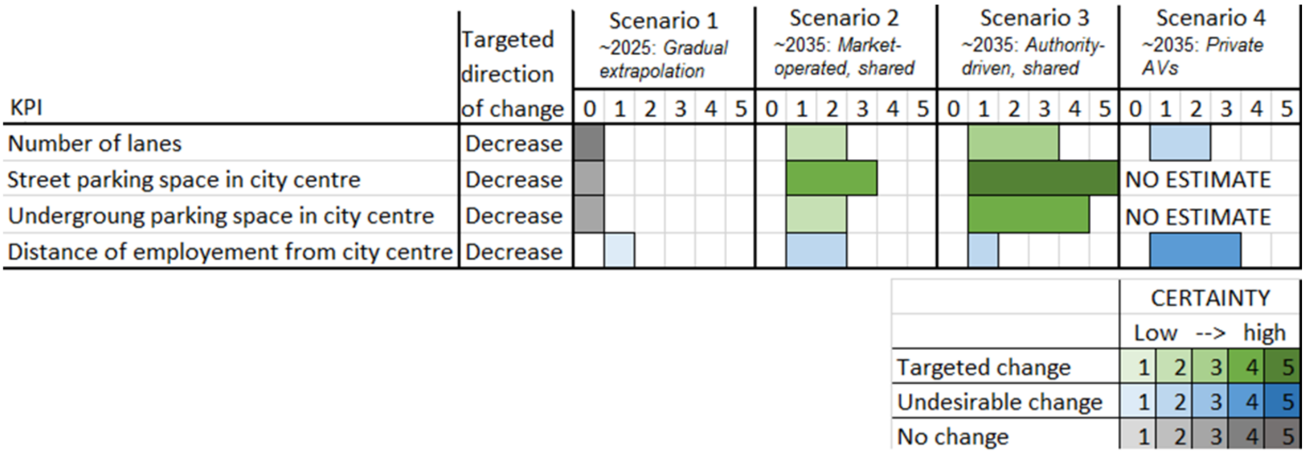
Total mileage travelled by active modes of transportation, walking and bicycle, was not estimated to increase in any of the given scenarios. In scenarios 1, 2 and 3 there was estimated to be no or a slight change in usage of active modes. It was assumed that the increase in comfort from automation is offset by more shared mobility. In scenario 4, it was assumed that the comfort of automation and private ownership of automated vehicles would lead to a considerable decrease in use of active modes.

It was estimated that automated mobility services would lead to improved access to services, which would be a positive impact regarding public health and safety. The most positive impacts were assumed in scenario 3, where also the greatest decrease was estimated in the number of injuries and fatalities due to automation. In scenario 4, automation of private cars makes a difference in reducing fatalities, but still there are many private cars being used that might cause a higher accident rate than in scenario 3. There was no consensus on the impact of automation on social isolation or people.

Land use

The estimated impacts of AD on land use are presented below in Table 6 from a societal point of view.

Table 6. Estimated land use impacts for the society (scale: 0=no change, 5=large change).



Considering parking space in city centre areas (on street of underground), in scenarios 1 and 4 there are presumably more private cars in city centres and therefore a higher demand for parking space. Car sharing and public transport decrease the need for parking space. Although automated parking functions have the potential to reduce the space needed for parking, the impact is not considerable as long as there is a substantial number of cars without automation in parking areas as well.

When it comes to street parking space in city centre areas, in scenarios 1 and 4 there are more private cars in city centres and therefore a bigger demand for parking space. Car sharing and public transport decrease the need for parking space.

The development of automation and transport systems makes it possible and more attractive to commute longer distances, and thus the location of employment (distance from the city centre) is assumed to increase.

The number of lanes is estimated to drop in scenarios 2 and 3 because of the increase of shared mobility and decrease in number of private cars. No effect is assumed yet in the short term, but in the long term there would be more cars and thus more lanes (scenario 4). It was assumed that AD is not based on dedicated lanes.

Economic analysis

The estimated impacts of AD in terms of economic analysis are presented below in Table 7 (benefits) and Table 8 (costs and investments) from a societal point of view.

Table 7. Estimated impacts considering economic benefits for the society (scale: 0=no change, 5=large change).

KPI	Targeted direction of change	Scenario 1 ~2025: *Gradual extrapolation* (0 1 2 3 4 5)	Scenario 2 ~2035: *Market-operated, shared* (0 1 2 3 4 5)	Scenario 3 ~2035: *Authority-driven, shared* (0 1 2 3 4 5)	Scenario 4 ~2035: *Private AVs* (0 1 2 3 4 5)
Growth of automotive industry	Increase				
Growth of transport services sector	Increase				
New established businesses	Increase				
Total factor productivity	Increase				

	CERTAINTY Low --> high				
Targeted change	1	2	3	4	5
Undesirable change	1	2	3	4	5
No change	1	2	3	4	5

Table 8. Estimated impacts considering economic benefits for the society (scale: 0=no change, 5=large change).

KPI	Targeted direction of change	Scenario 1 ~2025: *Gradual extrapolation* (0 1 2 3 4 5)	Scenario 2 ~2035: *Market-operated, shared* (0 1 2 3 4 5)	Scenario 3 ~2035: *Authority-driven, shared* (0 1 2 3 4 5)	Scenario 4 ~2035: *Private AVs* (0 1 2 3 4 5)
Capital cost per CAD vehicle	Decrease				
Operating cost for the deployed system	Decrease				
Cost of purchased automated vehicle	Decrease*				
Investment cost for digital infrastructure & connectivity network	Decrease				
Operation & maintenance cost for digital infrastructure & connectivity network	Decrease				
Investment cost for physical infrastructure	Decrease				
Operation & maintenance cost for physical infrastructure	Decrease				
Cost per trip for user	Decrease				

*Targeted direction of change can be both decrease (for mobility operator) and increase (for carmaker).

	CERTAINTY Low --> high				
Targeted change	1	2	3	4	5
Undesirable change	1	2	3	4	5
No change	1	2	3	4	5

The reasoning behind the economic analysis estimates was as follows:

- For the KPIs related to productivity or work time gained, the long-term scenarios were ranked higher due to the higher level of automation and safety, and among them scenario 3 was the highest due to the high efficiency of multi-modality.
- For the KPIs related to growth and interest from investors, all of them show a positive trend. But for scenarios 1 and 4 with a high level of private cars, the benefits are higher for the auto industry.
- For the KPI related to the job market, the expected impact is rather negative for scenarios 2 and 3, which lead to fewer bus and taxi drivers.
- For all the KPIs related to investments or operation and maintenance costs, the expected impacts are an increase, with higher magnitude for scenarios 2, 3 and 4 due to the higher technology complexity and integrity needed for level 4 automation.
- For the KPIs related to the cost of trips, no change is envisioned for scenario 1, but a decrease is expected for scenario 2 and 3, which have higher productivity. The KPI for scenario 4 with level 4 vehicles managed by fleets should also decrease, due to the higher efficiency of fleet management.
- For the KPI related to the cost of education, mixed effects are expected: it should increase because more challenging situations will be encountered during handover transitions. But if the Operational Design Domain of level 4 vehicles reaches a high level, then no driving skill may be required.
- The KPI for the insurance risk/benefit ratio should decrease for scenarios 2, 3 and 4 thanks to a lower accident rate. For scenario 1, the lower accident rate may be offset by higher repair costs.

Driving/driver behaviour

Maximum Speed v95

For scenarios 2–4, as there is higher CAD penetration than in scenario 1 it is likely that even more “speeders” will be removed from the distributions, because AVs are supposed to comply more with the rules than humans do. The CAD penetration rate will strongly affect the outcome, although it was felt that also non-automated vehicles would reduce their maximum speed.

Highway autopilot is likely to be a main CAD application in scenario 1. In scenario 2, additional functionality is added, including more complex traffic, but also more conservative AVs. This means that the maximum speed may be reduced even further. With higher CAD penetration, even more “speeders” will be shifted down to lower speeds, but the variability in speed will be reduced.

In scenario 3, public authorities are pushing forward and there may be dedicated lanes for CAD. Speed is likely still reduced but may be somewhat higher than for scenario 2 due to the dedicated lanes. Conservative AVs will reduce maximum speed.

In scenario 4, private put complex (more than highway autopilot) functions likely mean a similar reduction to that in scenario 2. A private push for the services may result in somewhat higher speeds.

Average Speed

Changes are similar to those for v95.

Eco-Driving

The overall effect should be positive (better eco-driving performance). As AVs become more common (scenarios 2–4), eco-driving will improve overall (thus Scenario 1 will have worse total-traffic eco-driving performance compared to scenarios 2–4).

Unnecessary decelerations/low speed due to VRU

VRU (vulnerable road user) interactions are going to be a main issue for Scenarios 2–4, while for scenario 1, with primarily highway autopilot functionality, the effects will be limited.

Scenario 1: Not (much) applicable to highway autopilot. The effect of the few VRU interactions will not be noticeable.

Scenario 3: With public authorities possibly enabling dedicated lanes for CAD transit, the number of VRU interactions, and thus unnecessary decelerations, may be lower than for scenarios 2 and 4.

Time headway

AV settings will likely be higher than the average time headway (THW) of manual drivers in most of Europe, increasing the THW overall across all scenarios. It is uncertain what the AV THW settings of the future will be, both in terms of technological achievements and the willingness of OEMs/legislators to take “risks”. The number of cut-ins ahead of AVs (both rural and urban), and driver acceptance of such, are likely to be a driving factor for both THW setting strategies. V2V connectivity will also affect THW changes for AVs (with/without connectivity).

In platooning, THW will of course be lowered compared to the manual driving of today.

Post encroachment time (PET)

For scenario 1: As highway autopilot is likely to be the main technology in this scenario, and there will basically be no intersections for that technology, PET is not applicable to Scenario 1 to any major extent.

For scenarios 2–4: PETs are likely to increase, as several technologies/applications in these scenarios are believed to apply to relatively defensive driving. However, extremely long (manual driving) PETs may also decrease, making the average change uncertain (could also decrease). In addition, the uncertainty about how much V2V and V2I connectivity there will be in 2035 makes the PET change estimates uncertain. However, even though better connectivity may enable a reduction in PETs, it would only be possible to implement at intersections where all vehicles/road-users are connected, which will likely be very few by 2035. Also, user acceptance of a short PET is likely to take a while to pick up.

Adaptability to traffic conditions

Scenario 1: Highway autopilot is quite predictable, and connected vehicles would make it even more so. However, with the short horizon (2025) it is unlikely that the V2V and V2I applications will have much effect. There the changes may be minor (or possibly even decreased adaptability with defensive/conservative driving).

Scenarios 2–4: With the longer time-horizon, connectivity is likely to have a larger impact on adaptability. However, other applications (e.g. urban with VRU interaction) may limit the adaptability with respect to VRUs. VRUs may affect the adaptability a lot (decrease it), but here we assume good technological development with respect to VRU predictions.

Reaction time

The reaction time (in a critical situation) will decrease drastically for all scenarios.

The estimation of driver behaviour in the long-term scenarios is summed up in the table below, in which the scale indicates the direction and magnitude of change.

Table 9. Estimated driver behaviour impacts in the long-term scenarios (scale: -5=large decrease, 0=no change, 5=large increase).

	Change in the long-term scenarios										
KPI	-5	-4	-3	-2	-1	0	1	2	3	4	5
Maximum Speed v95			■	■	■						
Average Speed				■	■						
Eco-Driving							■	■			
Unnecessary decelerations/low speed due to VRU						■					
Time headway							■				
Post enchroachment time						■					
Adaptibility to traffic conditions							■	■			
Reaction time		■	■	■	■						

Energy and environment

Overall, the effects on energy and the environment were regarded as small. The differences of the effect between the four scenarios were not assessed, but rather the changes in the long-term scenarios in general (Table 10).

Table 10. Estimated energy and environment impacts in the long-term scenarios (scale: -5=large decrease, 0=no change, 5=large increase).

	Change in the long-term scenarios										
KPI	-5	-4	-3	-2	-1	0	1	2	3	4	5
Energy savings due to reduced air resistance							■				
Energy use for in-car IT technology							■				

Network efficiency

Road capacity

Scenario 1: Although all new cars have an option for SAE L2 (traffic jam assist, lane keeping assist and parking assist), and SAE L3 functions have been introduced (traffic jam assist, lane keeping assist and parking assist), L3 for freight and L2 and L3 for PT, the penetration levels of these vehicles on the roads are low.

Most (>80%) vehicles are L1 or below. The road capacity for all roads may decrease slightly due to the mixed traffic.

Scenarios 2–4: A higher automation level, higher penetration of CADs in traffic, but not nearly in the neighbourhood of 100%. Scenario 3 differs from Scenarios 2 and 4 in the urban environment in that travellers make more use of large vehicle public transport, and there are some dedicated lanes for public transport present.

Scenario 4 sees more private vehicles on the road. Scenario 2 differs from Scenario 4 in that private vehicles can be shared, like automated shared taxis.

The motorway road capacity for all scenarios 2–4 will be similar. On the motorway in these scenarios, at a 40% penetration rate on motorways the impact of CADs due to communication may slightly improve capacity (assessment based on simulation results surveyed in Quick Scan of the Potential Impacts of Speed Management Measures [Wilmink et al. 2013]). However, in busy and complex traffic situations it is unclear whether CADs can realize the improved capacity.

The urban environment for Scenario 3 is influenced by the use of public transport, some of which is on dedicated lanes. In comparison with Scenario 2, where PRTs in the suitable environments may play a role, and Scenarios 4 with more privately operated PRTs & shuttles in mixed traffic.

Travel time per road-km

The total or average travel time will most likely increase in all scenarios on motorways and urban roads. This is assuming that the systems will not be used on rural roads, as per the concept descriptions.

Intersection capacity

Most of the signalized intersections are on roads where traffic volumes are high.

Scenario 1: Most (>80%) vehicles are L1 or below. The capacity at signalized intersections may increase slightly with the presence of CADs. The capacity at unsignalized intersections may drop slightly due to the presence of CADs.

The net impact of higher traffic volumes at signalized intersections could be a slight increase.

Scenarios 2–4: Higher automation level, higher penetration of CADs in traffic, but not nearly in the neighbourhood of 100%. Scenario 3 differs from Scenarios 2 and 4 in the urban environment in that travellers make more use of large vehicle public transport, and there are some dedicated lanes for public transport.

Scenario 4 sees more private vehicles on the road. Scenario 2 differs from Scenario 4 in that the private vehicles can be shared, like automated shared taxis.

See scenario 1 for the analysis of intersection capacity for scenarios 2–4. If more information were obtained about how traffic volumes are affected (from group 1 or group 3), the analysis here could be extended.

The estimation of network efficiency in the long-term scenarios is summed up in Table 11 below.

Table 11. Estimated network efficiency impacts in the long-term scenarios (scale: -5=large decrease, 0=no change, 5=large increase).

KPI	Change in the long-term scenarios										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
Road capacity						■					
Travel time per road-km							■				
Intersection capacity						■					

6.3. Automated driving service-based impact estimates

The preceding chapter discussed evaluations of driver behaviour, energy and environment and network efficiency impacts. As explained in the methodology, for these impact areas it was considered more suitable to evaluate the impacts based on AD services than the scenarios. The scenario-based estimates derived from service-based estimates, which were done first and are presented in Tables 12–14, are discussed in greater detail below.

Table 12. Service-based impact estimates for driver behaviour (scale: -5=large decrease, 0=no change, 5=large increase).

	Highway Autopilot /cars											Urban & Suburban Pilot											Automated Valet Parking											Private operated, Automated Personal Rapid Transit (PRT)/Shuttles in Mixed Traffic											Public operated, Automated buses (and trams) in Mixed Traffic										
KPI	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5
Maximum Speed v95			■	■	■								■	■	■	■												■								■	■	■										■	■						
Average Speed				■	■								■	■	■	■												■								■	■	■										■	■						
Eco-Driving							■	■										■	■									■												■	■										■	■			
Unnecessary decelerations due to VRU						■												■	■									■												■	■										■				
Time headway							■											■	■	■								■												■	■										■	■			
Post enchroachment time						■												■	■									■												■	■										■	■			
Adaptibility to traffic conditions						■								■	■	■												■									■	■												■					
Reaction time		■	■	■	■								■	■	■	■									■	■	■									■	■	■								■	■	■	■						

Table 13. Service-based impact estimates for energy and environment (scale: -5=large decrease, 0=no change, 5=large increase).

	Highway Autopilot /cars											Urban & Suburban Pilot											Automated Valet Parking											Private operated, Automated Personal Rapid Transit (PRT)/Shuttles in Mixed Traffic											Public operated, Automated buses (and trams) in Mixed Traffic										
KPI	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5
Energy savings due to reduced air resistance							■										■											■											■											■					
Energy use for in-car IT technology							■											■	■	■	■								■	■	■	■	■							■	■	■	■								■				

Table 14. Service-based impact estimates for network and efficiency (scale: -5=large decrease, 0=no change, 5=large increase).

	Highway Autopilot /cars											Urban & Suburban Pilot											Automated Valet Parking											Private operated, Automated Personal Rapid Transit (PRT)/Shuttles in Mixed Traffic											Public operated, Automated buses (and trams) in Mixed Traffic										
KPI	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5	-5	-4	-3	-2	-1	0	1	2	3	4	5
Road capacity						■											■											■									■	■												■					
Travel time per road-km							■											■										■												■											■				
Intersection capacity						■												■										■												■										■						

Driver behaviour

The overall pattern is quite similar for all KPIs except automated valet parking. In the following the assumed effects are described by KPI:

Maximum speed v95

The standard deviation of speed will be smaller, but a small decrease in maximum speed is likely (95th percentile), as the CADs likely are not allowed to exceed the speed limit – practically cutting away the speeder portion of the distribution for the CADs and influencing other traffic too (manual drivers may be forced to stay behind slower-moving vehicles). There may be major differences between countries.

Average speed

The same arguments as for the maximum speed KPI. The average speed will likely decrease, but this is relatively uncertain as it strongly depends on CAD software/settings (e.g. defensive/careful driving).

For many individual drivers, the added time spent in the car will likely not be a major issue, at least for higher levels of automation and for work commuting, as they can then do other things.

Eco-driving (degree of how the actual driving style (of the fleet) accords with the optimal driving style on the perspective of energy efficiency)

Eco-driving works. It is a matter of implementing the eco-driving style in vehicles. Connected vehicles can anticipate a traffic situation much better than human drivers (e.g. the connected car knows when a traffic light is about to change and can calculate its optimal speed). CADs will thus on average drive in an eco-friendlier manner than manual drivers. Manual traffic may be frustrated by CADs (e.g. not violating speed limits, at least in some countries), trying to overtake over and over again, adding a large amount of unnecessary accelerations and decelerations, which could affect this KPI negatively on a traffic (not CAD) level. However, eco-driving should not affect the average speed, and also manual drivers will understand that unnecessary accelerations are not helpful.

At high speed, (unnecessary) accelerations need more energy than at low speed. Thus the potential energy savings are greatest on highways. However, in urban surroundings, traffic flow is less steady and more acceleration is needed. No significant savings are possible for valet parking. Buses and larger vehicle CADs have the potential to save significantly on fuel with CAD, especially as scenarios 2–4 are likely to have a relatively conservative/defensive CAD driving style for public transport with larger vehicles.

Unnecessary decelerations/low speed due to VRU

Overall, the issue with VRU interactions will very much depend on technical CAD performance in the interaction with VRUs (e.g. predicting intentions correctly). Defensive/ conservative driving styles may require unnecessary decelerations when there are many VRUs present.

VRU behaviour changes may also strongly affect the interaction and number of unnecessary decelerations. If, for example, pedestrians and cyclists in urban environments learn that CADs will stop if they enter the roadway, and trust that they will, many VRUs may take advantage of this feature to cross roads etc. in a way they would not do with manual drivers (which they may not trust to stop in time).

Time headway

CAD settings will likely be higher than the average THW of manual drivers in most of Europe, increasing the THW overall, across all scenarios. It is uncertain what the CAD THW settings of the future will be, both in terms of technological achievements and the willingness of OEMs/legislators to take risks. The number of cut-ins ahead of CADs (both rural and urban), and driver acceptance of such, are likely to be a driving factor for both THW setting strategies. V2X connectivity will also affect THW changes for CADs (with/without connectivity). Long term (well beyond 2035), when the penetration rate is very high and systems are very reliable, the THW may again be significantly smaller (with good V2X). Note that platooning is not considered in here, for which the THW naturally would be lower.

Post encroachment time (PET)

When intersections are negotiated, the standard deviation of PET is likely to be reduced with CAD. It is uncertain to what level.

Adaptability to traffic conditions

The adaptability to traffic conditions will likely increase, but only to a minor extent, unless V2V and V2I applications get very strong penetration.

Reaction time

The reaction time (in a critical situation) will decrease drastically for all scenarios. The reaction time for the fastest reacting drivers may be faster that the average CAD reaction for some time yet (given that CAD algorithms will need to be quite sure to issue avoidance commands and interpret/predict situations), but long term and also early, all driver distractions/inattentions and other “reaction time” increasers will not be applicable to CADs.

Energy and environment

The higher the speed (and thus the air resistance), the higher of course can be the effect of driving in wind shadow. Thus, services on high speed roads (highways) might have the most effect, whereas services at low speed like the parking pilot or traffic jam pilot clearly will not be able to improve in this area.

We did not expect energy savings due to reduced air resistance in the applications Urban & Suburban Pilot, Automated Valet Parking, Private operated, Automated Personal Rapid Transit (PRT)/Shuttles in Mixed Traffic or Public operated, Automated buses and trams in Mixed Traffic.

The only service assessed to have an effect is the highway pilot or, to be more precise, the highway convoy. Even in this application the group agrees that the effect will be rather small for the following reason: the front surface of cars is smaller and the wind shadow is less effective than with trucks. The main question, however, is how many ad-hoc convoys will be built at all. The ERTRAC roadmap remains quite vague in this respect: “Depending on the deployment of cooperative systems, ad-hoc convoys could also be created if V2V communication is available.”

The importance of ad-hoc convoys in general and the difference between the (long-term) scenarios in particular is quite small. Thus, the changes are assessed as very small and should be seen more as a reminder. The reason for the small contribution of automation to this KPI is also that we did not assess freight transport, where a much higher effect can be expected.

There is no doubt that energy use for in-car IT technology will increase with automation. Since no figures about (future) demand of energy for in-car IT technology are available, we made some rough calculations to get some idea of this dimension.

	Highway	Urban Car	Urban Bus/Shuttle	Parking
Av. Speed [km/h]	100	40	40	15
KWh/100km	30	15	50	20
KWh/h	30	6	20	3
Demand [W] driving	30,000	6,000	20,000	3,000
Demand [W] IT (guess)	500	500	500	500
Percentage	1.7%	8.3%	2.5%	16.7%

Note: Energy demand is calculated for E-cars. It can be assumed that the electrification of power trains will advance within the next few years. Electricity for cars with an ICE (internal combustion engine) has to be produced with a low degree of efficiency, which means that although the energy consumption for the drive train of these cars is higher, the proportion will not change significantly.

Although the above figures are only rough estimates, some statements can be made as follows:
- Energy use of in-car IT cannot be neglected.
- Energy consumption for automation of shared vehicles/mass transit comes less into effect than for private cars.
- For stand-by and low-speed applications, in-car IT needs a significant proportion of energy.
- Although the estimations are fraught with uncertainty, the common-sense consensus within the group was that the amount of energy needed for in-car IT will increase.

According to the diffusion of applications, scenarios with a higher proportion of private cars/parking pilots will have a higher demand for energy.

Network efficiency

Road Capacity

Low percentages of CADs in the traffic stream will only slightly affect road capacity. As the percentage of CADs in the traffic stream increases, the road capacity may decrease. This is due to discontinuities, such as entrances and exits, weaving sections and lane drops, where lane changing needs to take place. Only at high penetration rates can communication between vehicles be used to create suitable gaps, which may allow the road capacity to increase.

More homogeneous speeds of drivers (smaller standard deviation of vehicle speeds) can result in fewer shockwaves, hard braking, etc., which in turn lead to increased road capacity; on the other hand, lane changing becomes more difficult (decreased road capacity), unless the majority of vehicles can communicate so that suitable gaps can be created.

Rural roads have a general speed limit in the EU member states of 80–100 km/h (Current Speed limit Policies of the EC, website consulted august 1, 2018). Thus, rural roads are unaffected by CAD due to the speed limit of Urban and Suburban Pilot of 50 km/h, and the other concepts are not used on rural roads.

Total or average travel time per road-km

Average speed: It is likely that there will be a small decrease in maximum speed (95th percentile), as the CADs likely are not allowed to exceed the speed limit, practically cutting away the speeder portion of the distribution for the CADs and influencing other traffic too (manual drivers may be forced to stay behind the slower moving vehicles). This will reduce average speed (reference driver behaviour) and increase total travel time.

Intersection capacity

Intersections are challenging environments for automated vehicles. When signalized, communication of SPAT messages from traffic light installations can assist the CADs. At a signalized intersection, communication and quicker sensing by CADs enables a decrease in the time needed to react to the cycle change from red to green, allowing vehicles to synchronize their acceleration through the intersection. However, the first vehicle to cross the stopping line must first determine whether the intersection is empty of conflicting streams. All vehicles should determine whether the intersection is empty of other road users who may not be observing the traffic rules, like a car turning right when a cyclist is going straight on and has a green or red light. If there are often chaotic situations at intersections (traffic rules not being observed), the CAD might not be able cope with this as well as manually-driven vehicles. THWs will likely increase (reference driver behaviour analysis), but in the case of signalized intersections where vehicles accelerate from a stopped position, the THWs at lower speeds could be smaller than those of human drivers.

Dedicated lanes for public transport used mostly on roads with signalized intersections mean that there is an additional traffic stream that needs to be included in the signal cycle, which generally leads to a decrease in intersection capacity due to the need for intersection clearance times. Thus, the placement of a dedicated lane at an intersection, which takes space and time, needs to be balanced against the benefits it generates.

The absence of signalling at an intersection will require safety buffers to be introduced. Gap acceptance parameters will change, compared to human drivers (acceptable gaps are likely to be larger than for human drivers). The buffers can include increased distances to other vehicles and reduced speeds when approaching and crossing the intersection.

The more complex the environment, the more uncertain the impacts will be. For instance, if there is a lane drop a few hundred metres after the intersection, the question is how automated vehicles will deal with the lane drop, with potential blocking back effects, e.g. if the merging process is inefficient.

If there is mixed traffic, and the CADs are not suitably improved for identifying gaps etc., then the intersection capacity at unsignalized intersections may decrease.

The scenarios dictate that mixed traffic is present in all environments, varying from a 50% equipment rate for highway autopilot (cars) to 25% for Urban and Suburban Pilot (USP) equipment. At very high automation levels (nearly 100%), great improvements in intersection capacity are possible, although none of the scenarios describe this situation.

7. Mapping of projects and expected outcomes

7.1. Mapping of ongoing evaluation studies

A template was created to collect information about ongoing and very recent studies in Europe. The template was sent to the experts involved in the studies. Input was received on 11 projects (INFRAMIX, ENSEMBLE, PROSPECT, i-CAVE, C-MobILE, AdaptIVE, DRAGON, Testbed Lower Saxony (TF NDS), TrustVehicle, AUTOPILOT and L3Pilot).

We analysed which impact areas and KPIs are expected to be covered by upcoming project results. In five impact areas – acceptance and use, travel behaviour and mobility, public health, land use and economic analysis – the expected project outcomes were compared with the certainty of the expert groups on the impacts expressed in this work. The aim of the mapping was to reveal future research needs.

Some observations are listed (Figures 4–12) below:

- Almost all projects in the data address user acceptance and use. Among these KPIs, 'inappropriate use', 'feeling of comfort', 'negative feelings' and 'motion sickness' were least in focus. In the expert assessment, certainty was moderate regarding 'use' and 'feeling of safety' – the ongoing studies are expected to contribute to both topics.
- Experts' certainty about mobility impacts was low or moderate, except for 'journey quality' for which there was a high degree of certainty. New knowledge is expected from six studies.
- The certainty of estimates of the KPIs describing public health was moderate – new results are expected from six studies.
- Four projects have somewhat addressed land use. The certainty of the estimates was low.
- Regarding economic impacts, the certainty in assessing costs was high. Cost-benefit and stakeholder analyses were addressed in quite a few studies (eight and six, respectively)
- Driver behaviour KPIs were among the most frequently studied.
- Traffic safety was studied in eight projects.
- Environmental KPIs (specifically impacts on surroundings and noise) have not been studied much.
- Network efficiency was studied in quite a few studies but 'capacity' less so.

Figure 4. Projects covering impacts on use and acceptance of automated driving. Certainty refers to the degree of certainty of expert groups on the impacts (in one direction or the other).

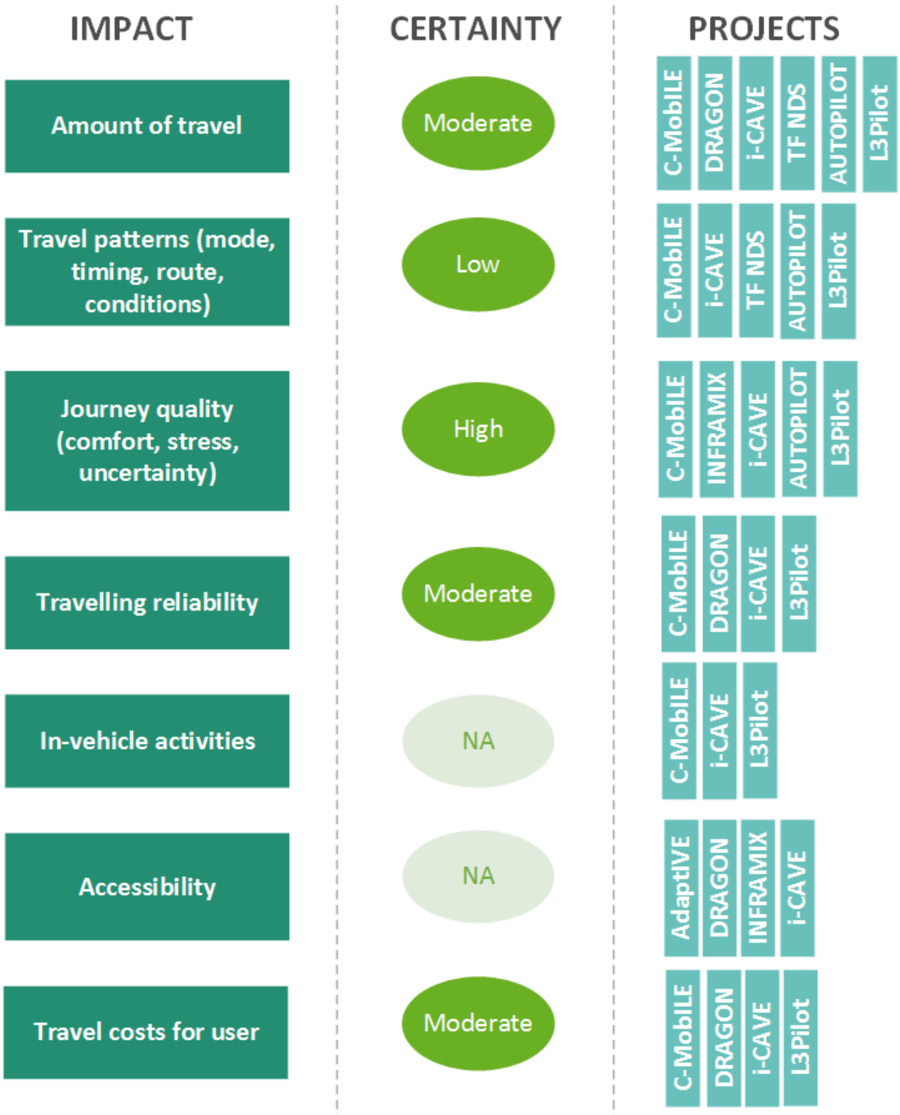


Figure 5. Projects covering travel behaviour and mobility impacts. Certainty refers to the degree of certainty of expert groups on the impacts (in one direction or the other).

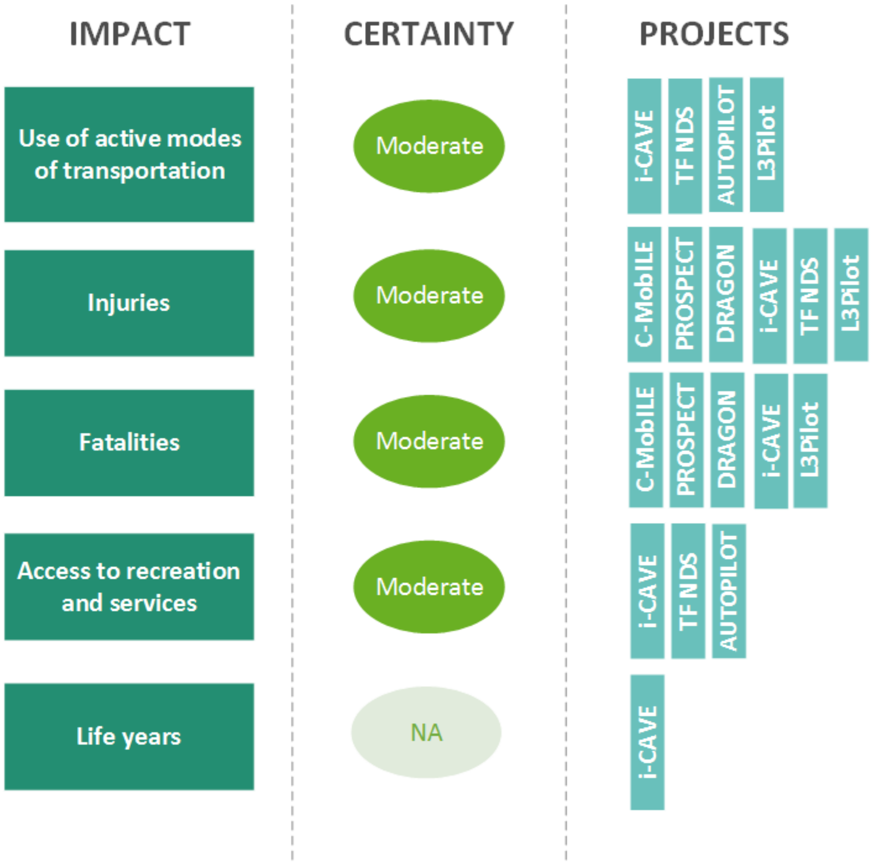


Figure 6. Projects covering impacts on public health. Certainty refers to the degree of certainty of expert groups on the impacts (in one direction or the other).

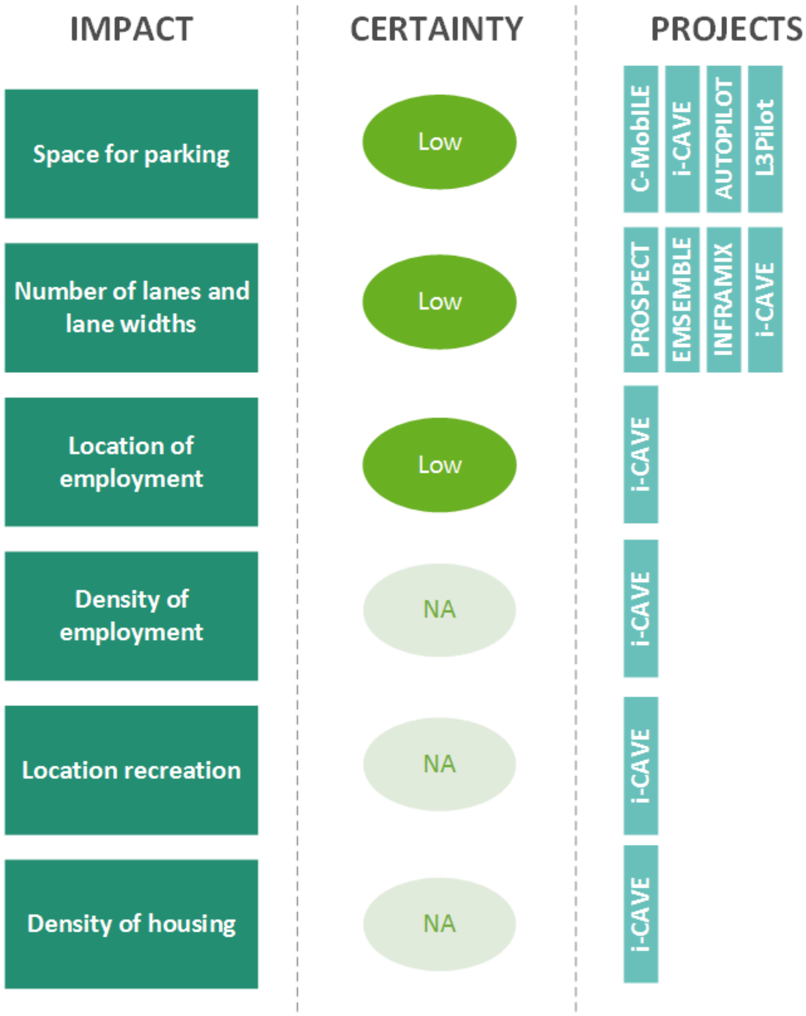


Figure 7. Projects covering impacts on land use. Certainty refers to the degree of certainty of expert groups on the impacts (in one direction or the other).

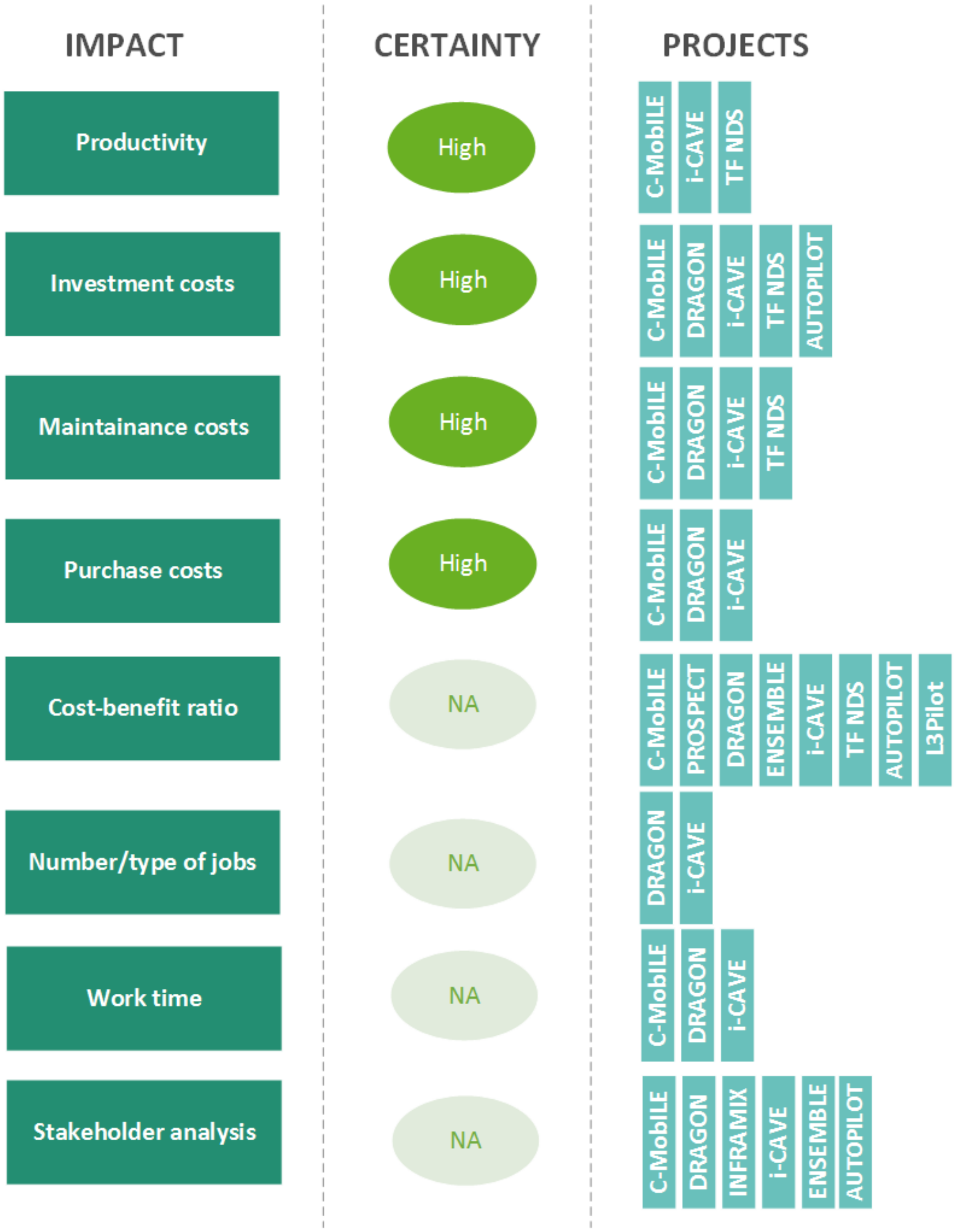


Figure 8. Projects covering economic analysis. Certainty refers to the degree of certainty of expert groups on the impacts (in one direction or the other).

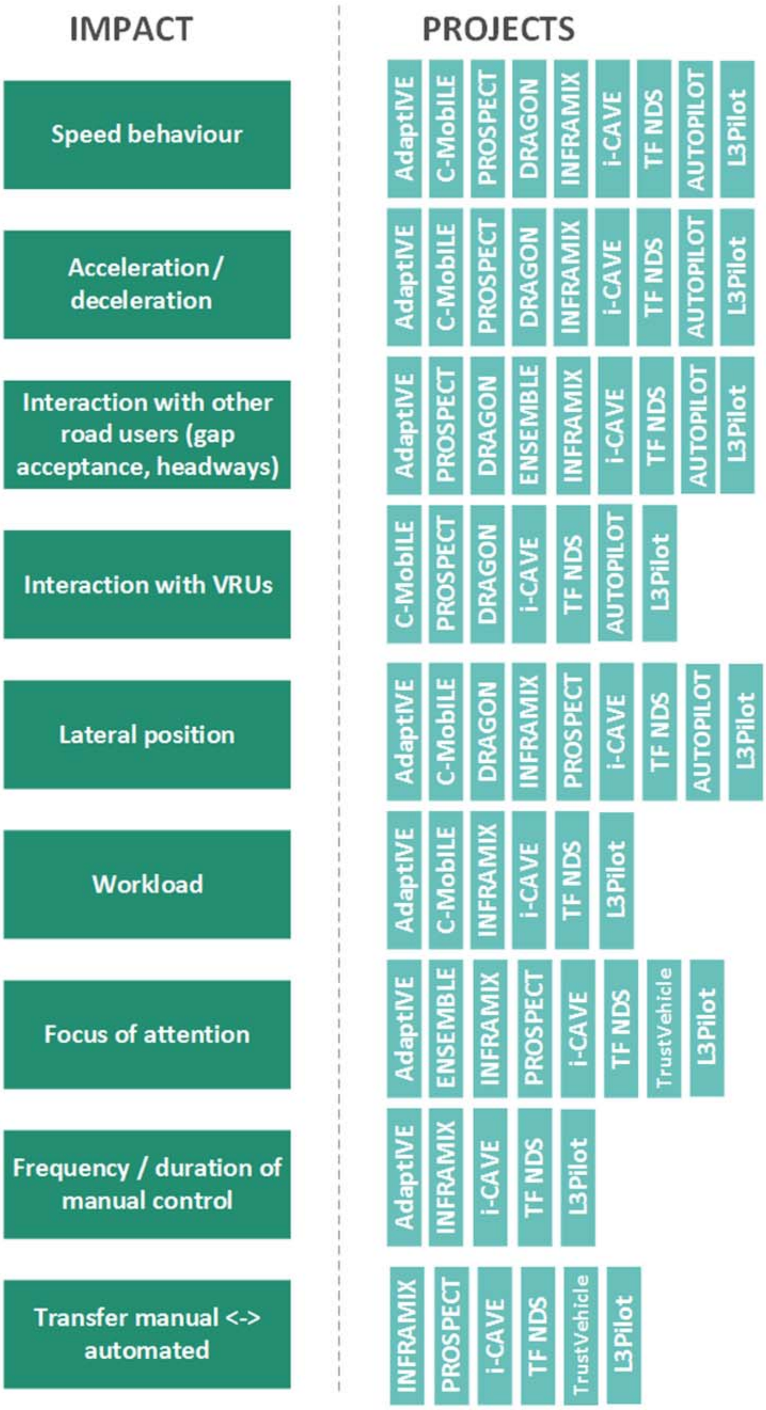


Figure 9. Projects covering impacts on driver behaviour.

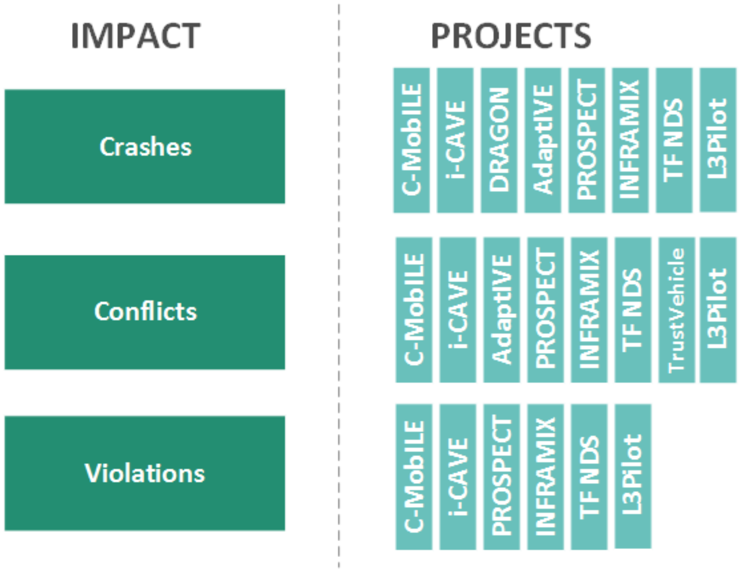


Figure 10. Projects covering impacts on safety.

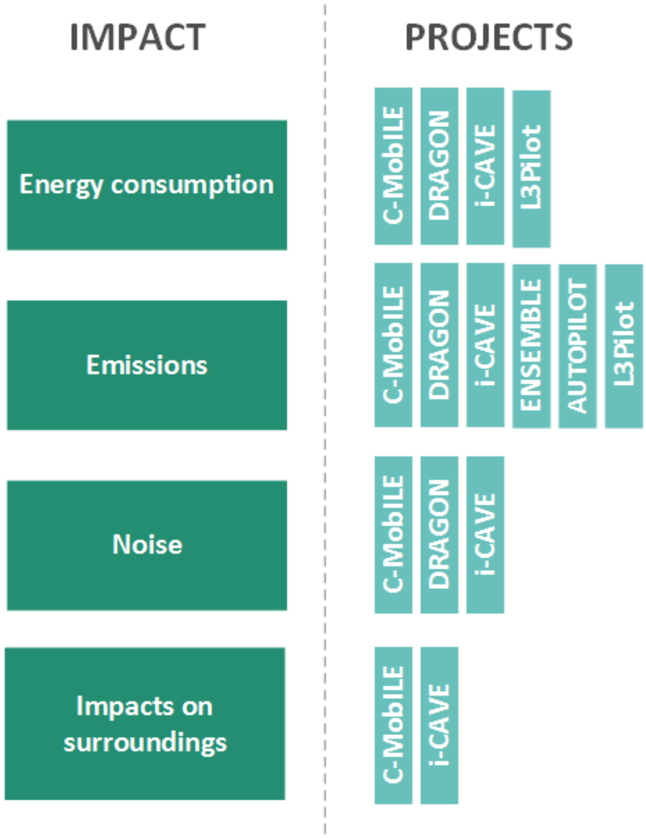


Figure 11. Projects covering impacts on energy consumption and the environment.

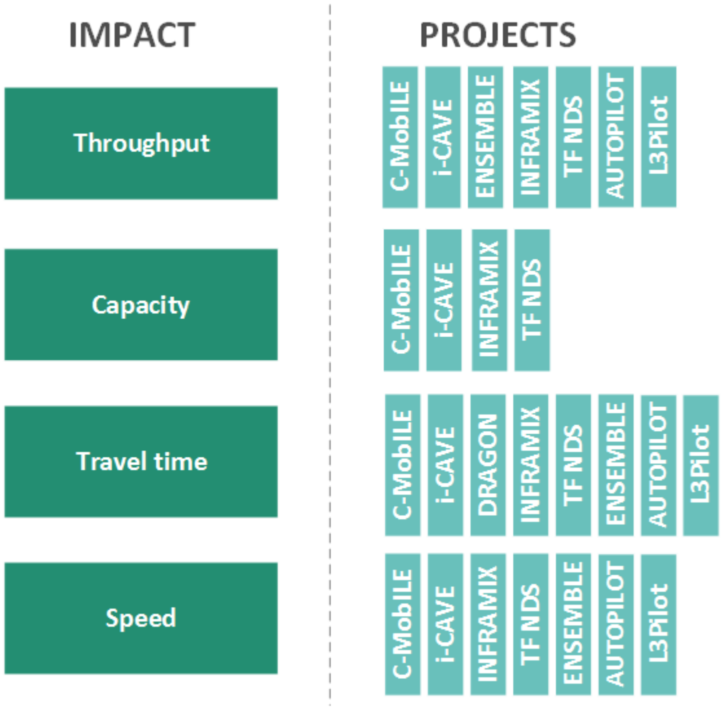


Figure 12. Projects covering impacts on network efficiency.

8. Discussion and conclusions

Assessment frameworks

The aim of the study was to compare the effects of AD in four selected scenarios. One scenario was a short-term scenario assuming that automation technologies are gradually focusing on a lower level of automation support. SAE level 3 would be introduced both in cars and trucks. The target year 2025 is quite close to today, and the expected effects are therefore very small for most KPIs.

The year of the long-term scenarios was roughly defined as 2035 – not very far in the future either. The automation service descriptions were taken from the recent ERTRAC road map (2017). The target year is closely linked with assumptions on how widely automation is expected to be a reality on the roads. Both the definition of system penetration and the target year (in the long term) were originally highly approximate: close to 2035, with a substantial share of automated vehicles on the roads. For most impact areas and KPIs this loose definition was enough, and the estimates were provided from that perspective.

However, for assessing driver behaviour, network and environmental impacts, a more detailed analysis was needed. Automation services were specified in greater detail, and system penetration was assessed separately taking into account not only vehicle penetration but also ODD, vehicle mileages in ODD and usage, thereby ending up with more realistic estimates. An important finding is how greatly the penetration in real use on the roads decreases when all contributing factors are considered. The estimates for this group appear also to be more precise, as the scale was defined explicitly. For the other impact areas (user acceptance and use, mobility, land use, public health, and economic impacts) the use of a scale (from 1 to 5) was subjective and focused more on a comparison of scenarios than the provision of absolute values.

Not only did the scenario definitions address the maturity and use of automation technologies, but some additional variables were determined. The dimensions were taken from recent scenario studies in Sweden and the Netherlands. The third key reference was a discussion paper by POLIS. Due to the nature of the work, the number of scenarios was kept small; we did not vary the factors systematically but created instead three long-term scenarios which were, to our understanding, possible or even plausible descriptions of alternative futures. The factors varied in the scenarios were the development of car sharing (whether successful or not) and locus of control (public authority-or industry-driven development).

The third important building block for the study was the reports of Trilateral ART Working Group (Innamaa & al 2018, Innamaa & Kuisma 2018). The impact areas and lists of KPIs were important materials on which the work was built. Originally, we intended to assess the nine impact areas as suggested by ART WG, but due in part to some practical issues we combined ‘public health’ and ‘safety’ into one impact area. The experts discussed and assessed the KPI lists; some KPIs were removed as they were difficult to assess in this type of work, while several new KPIs were added and estimated. This provided new information regarding KPIs.

Expert assessment as the approach

The work was based on the frameworks and background information described above, but even more so, on the expertise of the partners involved in the task. Thus its nature is subjective - an expert opinion balanced by mutual discussion. Furthermore, the experts formed three groups that acted quite independently of each other, but with the same introduction and instructions. In addition, the impact areas allocated to the groups differed from each other: some were more general and others more specific, which was also seen in the KPIs and choices the groups made.

Provision of the estimates was based on the substantial knowledgebase the experts had. Their expertise helped in structuring the work, posing questions and identifying relevant factors. The work was organized in sequential phases of individual work followed by discussion and reflection in the group and aiming to a consensus. The report aims to give insight into the process with the qualitative material addressed (e.g. Chapter 6.1, factors increasing/decreasing the effect). The qualitative and subjective nature of the work implies that several assumptions were made and reported regarding the estimates. Therefore, much research is needed to validate the results and get more accurate estimates. The tentative nature of the results is highlighted.

Before providing ratings of the magnitude of the change, the experts discussed the direction of the change. Regarding the direction of the change, the individual experts did not have the same opinion in the first phase. However, for many such disagreements, the discussion of the content and definition revealed different interpretations of the KPI. When these were clarified, a common understanding was found in many cases. Also, the lists of KPIs were reduced and some KPIs not easy to decide by the group were left out of the analysis. In addition, some new KPIs were suggested by the groups (compared to the work done by the ART WG). In all, the conclusion is that the lists of KPIs should be regarded as intended as a living document, new KPIs may emerge and the definitions as well as applicability of the KPIs needs to be checked and specified when applied.

Comparison of scenario based estimate

In the short term, the impacts were assessed as minor or moderate. The most substantial ones were assessed to be for user acceptance and use, but some costs were also expected even in the short term. The penetration rate strongly affects the estimates but also how connectivity (V2X) is going to proceed. Connectivity was assumed to highlight positive effects of automation.

Long-term scenario 3 (authority-driven and shared) appeared to be most beneficial for most impact areas, with scenario 2 (shared mobility) coming second. It is acknowledged that assessing whether a change is beneficial or not is a value based choice - our intention was to stress the societal and European transport policy perspective in presenting the results. The certainty of estimates was typically strongest for scenario 3.

A similar result emerged from a breakout session at the EUCAD2018 symposium, in which attendees were asked (using an interactive tool via mobile phone) to share their insights on the impacts of AD in the long-term scenarios defined in this work. According to the session report (Appendix 4), the group of nearly 40 attendees thought that the most beneficial impacts for society would arise from scenario 3.

Scenario 4 (private vehicles) was assessed quite negative for mobility and travel behaviour KPIs but to be most beneficial for economic growth. It is acknowledged that for some KPIs, whether or not they are beneficial for society is a question of values and cannot be classified easily.

Overall, when comparing the four scenarios, the experts seemingly considered the acceptance of AD to be good and that many benefits would ensue in the long term. In the short-term, the effects were assessed to be small, while at the same time it was estimated that there would be costs already that might pose a challenge to the deployment of automation.

Estimates by impact areas

Looking at the different impact areas, it appears that *user acceptance* was assessed overall to be quite high; the experts thought that automated driving would be accepted well and widely used. Even trust was assessed positively, although it has been identified repeatedly in discussions as a potential obstacle to the acceptance and use of AD (e.g. Kyriakidis & al 2017). This however, probably follows partly from the scenario descriptions; we assumed that only well-functioning products would be brought to market. Feelings of control may have been challenging to assess; on the one hand it could mean that the driver is relaxed and happy with the situation. On the other, it has been stressed that due to situation awareness it would be important to keep the driver in the loop (not losing their feeling of control) even if car driving is handled in automated mode for most of the time. System performance and reliability were identified as critical factors for most user acceptance KPIs.

For *mobility impacts*, the scenarios differed greatly from each other. Scenario 2 showed small impacts (more beneficial than negative), scenario 3 (authority-driven and shared) substantial benefits, and scenario 4 (private cars) some clearly negative effects. Accessibility and comfort were, however, assessed as beneficial in scenario 4. The effects were minor or none in the short term. However, comfort in travelling was expected to increase somewhat already in the short term. All scenarios assumed a slight increase in the number of trips. It is reminded that even small changes in this KPI may mean several remarkable changes on transport system level (in safety, efficiency, environment etc.). The reasoning was based on increase in comfort which is in accordance what was estimated regarding user acceptance KPIs. The pattern regarding *land use* was quite similar to that of mobility indicating some negative effects in scenario 4.

For *economic analysis* the changes between the scenarios are not substantial. In short term, the costs are somewhat smaller as for physical infrastructure in scenario 2 (shared mobility).

For *public health and safety* there were not many differences between scenario 2 (shared mobility) and 4 (private cars); scenario 3 (authority-driven and shared) appeared to be the most beneficial. Use of active modes was assumed to decrease in scenario 4 as comfort in driving automated cars increases. Safety benefits were addressed as part of public health:

saving of lives and injuries was assessed to be substantial specifically in scenario 3. The perspective of traffic safety was more public health-oriented than transport system-oriented.

There were substantial potential effects on *driver behaviour* – specifically speed, driving distances (in urban and sub-urban autopilot) and reaction times (in all services), which would lead to positive safety impacts. Driver behaviour KPIs are linked to several other impact areas; the relationship between average speed and traffic safety is one example. Low CAD penetration rates in 2025 and 2035 for many applications and operational domains across many European countries will strongly affect the overall benefit of CAD-related behaviour changes.

As a direct effect energy use can be affected by automation if the distance between vehicles will change (significantly) in the close-up range. This is only applicable to highway convoy and truck platooning (not included in the scenarios). *Network efficiency* impacts were assessed overall as being quite small. The main reason for the minimal effects was the assumed system penetrations (low, even if vehicle penetration assumed as reasonably big) and lack of automated functions designed for rural roads. Indeed, the considerations related to automation penetration (the Table ABCDE) demonstrates how remarkably the system penetration can fall down when all influencing factors are taken in into the calculations and thereby the impacts of automated driving.

Future research

In the second part of the study (chapter 7), we collected information about which KPIs are in focus in ongoing European projects. The result was compared with the uncertainty of estimates indicated by the experts. Eleven projects were addressed. It is quite hard to assess how well the sample represents the ongoing research activities.

As a general finding, expectations regarding the ongoing studies are quite high – all the topics seem to be under study to some degree. The results, however, do not tell how comprehensive the results are expected to be.

In the study, we compared uncertainty and expected results by KPIs. The analysis highlights the following topics for further research projects: negative aspects related to user acceptance, mobility impacts quite generally, effects on public health, land use and surrounding (noise), effects on network capacity. It is acknowledged that several KPIs and topics should be assessed more even if some results are expected in the near future from the on-going projects.

This report shows that a qualitative estimation of impacts provides good insight in key determinants and expected direction and even magnitude of change. Further consolidation of the results with studies, expert assessments, literature, pilot results and quantitative models will be an integral part of the CAD research in the common decade.

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Glossary: Acronyms and definitions

Term	Description
ACC	Adaptive cruise control
AD	Automated Driving
ADAS	Advanced Driver Assistance Systems
AMAA conference	International Forum on Advanced Microsystems for Automotive Applications
ART	Automated Road Transport
AV	Automated Vehicles
CAD	Connected and Automated Driving
CARTRE	EU H2020 ART06 CSA project CARTRE, GA number 724086
C-ITS	Cooperative Intelligent Transport Systems
ERTRAC	The European Road Transport Research Advisory Council www.ertrac.org
HAD	Highly Automated Driving
HF	Human Factors
IoT	Internet of Things
ITS	Intelligent Transport Systems
LTE	Long-Term Evolution mobile communications standard
MaaS	Mobility as a Service
MS	Member State
OEM	Original Equipment Manufacturer
PRT	Personal Rapid Transit
PTI	Periodical Technical Inspection
Public CARTRE website	Joint CARTRE-SCOUT website with the URL http://www.connectedautomateddriving.eu/
QoS	Quality of Service
SAE	Society of Automotive Engineers, international automotive and aerospace standards-setting body
SCOUT	EU H2020 project, Safe and Connected Automation in Road Transport
V2V	Vehicle to vehicle
V2X	Vehicle to everything

APPENDIX 1: Service descriptions for long-term scenarios

Passenger car service descriptions

Highway Autopilot including Highway Convoy

Highly automated driving up to 130km/h on motorways or motorway-similar roads from entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system but does not have to monitor it constantly. The driver can at all time override or switch off the system. There are no requests from the system to the driver to take over when the system is in a normal operation area (i.e. on the motorway). It is assumed that cooperative systems are widely deployed, and thus ad-hoc convoys can be created with the V2V communication available.

ODD: It can be assumed that the highway pilot will be available on all main highways; during exceptional very poor weather conditions (heavy snowfall in central and southern Europe), use of the highway autopilot will not be allowed, whereas construction areas can be passed in autopilot mode without restrictions.

In case of accidents or other unforeseen incidents, the highway autopilot brings, if possible, the car into a safe position and the driver can take over without any hurry.

Utilization: The deployment of the highway autopilot in each scenario is indicated in the table below. It is assumed that ~80% of cars equipped with the system will use it, especially during longer trips and in congestion (less on very short trips on the highway). Drivers appreciate that they can relax and have the possibility to engage with other things like mobile devices (which will commonly occur, because driving on a highway will become a very boring task).

Speed: Cars will comply with the speed limit but will also make use of it, which usually means driving at the speed limit, and the traffic flow will be more homogeneous and more relaxed than currently. Driving behaviour will also become more rational.

Safety distance: Although automated cars will react faster, they will keep more or less the same distance as non-automated cars. However, there will be some differences: the distance will be more homogeneous (fewer very short and thus dangerous distances, fewer very long and thus inefficient distances). Where cars create a convoy, the distance will be much shorter (0.5 seconds). In general, cars react less flexibly in unusual traffic situations.

Clearance of traffic jams works better, because vehicle operations can easily be optimized accordingly. Also, electrification contributes to more fluent driving especially in traffic jams.

Vehicle Kilometres Travelled (VKT): L4 passenger cars will allow passenger car drivers to use their time for other activities than driving within the ODD. This can affect the value of the time spent travelling in the car, even in the face of congested periods. VKT will most likely increase.

Urban & Suburban Pilot (USP)

Highly automated driving up to a limited speed in urban and suburban areas. The system can be activated by the driver on defined road segments, in all traffic conditions. The driver can at all time override or switch off the system.

Since automatization cannot offer full adequate functionality, or the related ODDs are limited (and the driver does not wish to activate/deactivate the system frequently), driving still remains the task of the driver, while some safety features are well accepted and in use.

However, the urban and suburban pilot is expected to become increasingly attractive. To mention a few examples:

Persons with disabilities who have a limited range of mobility but find the car quite helpful for daily errands will appreciate the new features, since it is either the only way to get around independently or they feel (and are) much safer using the new applications. Also persons without physical or mental disabilities but who feel unsafe or uncomfortable driving will appreciate that they can (partially) hand over their driving responsibility to the car.

“After party”: Driving home from a party can become safe even if the driver has not abstained from alcohol (or other intoxicants). Since speed is not that important in such cases, passengers will also accept an unhurried ride home. Because there is less traffic at night, slow cars with USP will not disturb other cars.

Busy managerial staff, artisans, etc.: Many people hurry from one appointment to another while having to manage a host of other things like phone calls, e-mails and forms. Those errands will be possible while driving an automated vehicle from its parking spot to a high-level street.

However, only 10% of the miles driven with capable cars are driven in automated mode.

ODD: USP is limited to streets in good condition, where pedestrians and cyclists are separated from motorized traffic and there is little traffic (sometimes USP can be limited to a certain time of day). However, it usually not allowed on streets with speed limits above 50km/h or in shared space areas. Thus, capacity is not relevant.

Speed: Cars with USP usually drive well below the speed limit, by about 10–20 km/h, especially in difficult situations (i.e. traffic with many pedestrians and cyclists). Acceleration and deceleration are usually soft and comfortable. In case of emergency, hard breakings are possible. The driving behaviour is rather defensive.

VKT: L4 USPs are limited in terms of the total number of kilometres driven due to the limited ODD and purpose. VKTs will not change.

Automated Valet Parking (AVP)

Highly automated parking including manoeuvring in a limited area with limited speed to and from most parking spaces. The driver can leave the vehicle and initiate manoeuvring of the car to the parking space by itself, using e.g. a smartphone or key. The driver does not have to monitor the system constantly and may initiate the parking-out manoeuvre the same way upon return.

ODD: Automated valet parking will be very common in areas with high parking demand like airports or shopping centres and event locations. However, since AVP is very comfortable, it is becoming widely accepted and practised nearly everywhere. This could cause major problems in high-demand areas since people might leave their cars to roam without finding a space. Thus in some cities new regulations are being implemented that regulate or prohibit the use of AVP in some areas. AVP is limited to areas with a speed limit of 30km/h.

Infrastructure is changing to meet the new requirements. Step in/drop off zones are becoming increasingly popular, while it will no longer be necessary to build a parking place as close as possible to the destinations. Parking can be used much more efficiently.

AVP is not only used in the traditional way of valet parking. Since more and more cars are becoming electrified, charging can also be automated and become more efficient and comfortable, especially at mobility hubs or intermodal changes like airports and railway stations.

Speed: Parking manoeuvres take place at a low speed of 20km/h and below.

Geometry: Automated cars can park very close and are thus space efficient. However, in many cases it is not possible to make use of the real benefit of narrow parking since pillars, geometry and other features are based on old requirements and there are still enough cars without a parking assistant.

Breaking: Since AVP cars usually drive without a passenger, it is possible to break very abruptly.

VKT: L4 AVP have a very limited ODD, thus the description above will change on the basis of the telco on June 14th. The actual kilometres driven may be influenced by the ease of parking, meaning that the hurdle of looking for a parking space will be removed. However, the distance between the parking area (where the AVTs can drive automatically) and the destination may negate the positive effect of driving around looking for a parking space.

Urban mobility vehicle service descriptions

Privately Operated, Automated Personal Rapid Transit (PRT)/Shuttles in Mixed Traffic

An automated shuttle drives in mixed traffic at the same speed as other traffic (maximum speed 40–50km/h) but has quite a defensive/conservative driving style (drives carefully). The infrastructure is checked thoroughly, and minor adaptions are made where needed to guarantee safe and easy travel, and difficult streets/areas are excluded from operation, but otherwise more or less the whole urban road network is covered by the service. However, roads with few pedestrians and cyclists are preferred.

ODD: In all streets where cyclists and pedestrians have their own lane and are separated from motorized traffic. This strongly depends on the street designs of the respective cities.

The service is operated by one or several private companies such as OEMs (e.g. Volkswagen) or IT companies (e.g. Apple, Uber).

The vehicles are relatively small (up to nine passengers). The service operates wholly on demand (no schedule, no fixed routes) and is not integrated with the city's public transport system.

That means that the service is door-to-door, but detours must be accepted.

Although the service itself is fully automated, it is still under constant surveillance of the operator, who can intervene in case of any problems.

To guarantee a good level of service, at least several hundred shuttles must be in use in one city. Use of the vehicle is shared (not exclusively used → robotaxi), but the average occupancy rate does not exceed 2–3 persons.

The prices for the passenger are somewhere between those of public transport and a taxi. They may change according to willingness to pay, as the provider may deduct the costs from the retired consumer's pension, for instance. New systems of automated fare collection are being developed.

VKT: PRTs are shared taxi services. Conventional thinking will lead to a reduced number of VKTs driven by private vehicles as a result of PRTs. They drive in mixed traffic at higher speed in an ODD with a limited number of VRUs.

Publicly Operated, Automated Buses and Trams in Mixed Traffic

An automated bus operates in mixed traffic on open roads at normal city traffic speed. Functions may include bus-trains, following and bus-stop automation for enhanced productivity, safety, traffic flow and network utilization. Automation leads to improved services and efficiency, but changes are more incremental than disruptive and not that noticeable to the customer (it does not matter to the customer if there is a driver in the metro/tram/bus or not).

ODD: The vehicles are mainly operated in controlled and semi-controlled environments to achieve undisturbed operations. The travel speed is thus higher than with privately operated shuttles. In addition, adaptation of the physical and digital infrastructure is developed/ adapted in close cooperation with the municipality, which leads to improved operation conditions and efficiency.

The service is operated by the public transport provider under public control. There may be different carriers, but they all operate under the umbrella of the public transport provider. The service is considered part of the mass transit system. Vehicles have different sizes but are bigger than shuttles (12–100+ passengers). The occupancy rate is better than with privately-operated shuttles, and vehicle use is very efficient.

The service is mainly operated with fixed schedules and routes, but on-demand services are also offered in special situations (e.g. night services). The service is fully integrated into the public transport system regarding schedules, route network, tariff system, information, apps, service centres etc., and a certain quality of service is guaranteed by public regulations.

The entire operation is supervised by the public transport operator.

VKTs: High-quality, automated public transport, if it is well-integrated with “first-” and “last-mile” transport, can significantly reduce VKTs in an urban environment.

APPENDIX 2: Scale for driver behaviour, energy and environment and network efficiency impact estimates

KPI	Increase (+) means…	Magnitude of change means
Maximum Speed v95	Higher speed	1=+1km/h, 2=+2km/h…
Average Speed	Higher speed	1=+1km/h, 2=+2km/h…
Eco-driving (No. of vehicles with energy-efficient driving style)	More efficient	0=75% (today), 1=5% more efficient, 5=as efficient as possible
Unnecessary decelerations/low speed due to VRU	More unnecessary decelerations	1=10% more, 2=+20%...
Time headway	Increase	1=+0.2sec, 2=+0.4sec…
Post encroachment time	Increase	1=+0.2sec, 2=+0.4sec…
Adaptability to traffic conditions	Adapts better	5=adapts perfectly and takes everything into account; -5=always the same behaviour (speed, safety distance etc.) whatever the weather etc.
Reaction time	Faster/better	1=10% faster (compared to humans), 5=need half the time or even less, -5=needs 50% longer or more
Energy savings due to reduced air resistance	Less energy use	1=-4%, 2=-8%, 5=-20% [fuel/km]
Energy use for in-car IT technology	More energy use	1=+2%, 2=+4%, 5=>10% (energy for IT compared to energy for driving)
Road capacity	More capacity	1=5% more, 2=10% more…
Total or average travel time per road-km	Average speed ~ average travel time?	1=5% more, 2=10% more…
Intersection capacity	More capacity	1=5% more, 2=10% more…

APPENDIX 3: Use and acceptance – KPI specific motivations for the scenario based estimates

KPI	*Comments Scenario 1*	*Comments Scenarios 2, 3, 4*
Number of instances where the driver must take manual control	As the level of automation increases, manual control by drivers decreases. Less for SAE level 2 than SAE level 3 or above	
Use of automated driving functions	Explicit in the scenario definition: it increases. Both for private cars and for public transportation, as driver or passenger	
Comprehensibility of user interface	It will first decrease and then increase, due to users' progressive habituation. More information is needed in the interfaces and therefore the complexity will increase, which will demand more efforts for the interface to be fully understandable, usable in avoiding errors and misinterpretations	
Requirement for attention and concentration on driving	Contradictory effects are expected: on the one hand we expect a decrease in attention during the AD driving phase (except in scenario 1 in SAE level 2) but a shift to cautious supervision and more attention during the transition phase. At the end, decrease of attention on the driving task in SAE level 4 private or public transportation.	
General feeling/acceptance of the general public	AD not that much deployed and probably not that well known by the public. Acceptance relatively low in this scenario, which means AD is rejected. Probably a transition phase where AD is still under examination and doubt	General acceptance is inherent in the definitions of scenarios, as AD is moderately to considerably deployed (depending on the cases)
Acceptance of AD by other road users	Likewise. AD not that much deployed and probably not that well known by the public. Acceptance relatively low in this scenario, which means AD is rejected. Probably a transition phase where AD is still under examination and doubt	General acceptance by users and non-users is inherent in the definitions of scenarios, as AD is moderately to considerably deployed (depending on the cases)
Trust (for CAD users)	Trust, reliability, usefulness and comfort are criteria for general acceptance. From the driver perspective, the acceptance measured by those criteria is continuously increasing if there is no crash. A crash or series of crashes might change acceptance levels	Similar to scenario 1 for drivers. Moderate trust and moderate comfort for passengers in scenario 4 due to less propension for shared mobility
Perceived reliability		
Perceived usefulness		
Perceived comfort		
Feeling of safety (from the perspective of vehicle users)	Positive otherwise would be not used. In scenario 4 however, the feeling of safety is too low for some potential users who decide not to use shared transport because of the absence of a driver.No safety feeling is available in the descriptions of scenarios regarding personal data protection.	
Feeling of safety (from the perspective of other road users)	Not applicable	
Feeling of being able to control the vehicle	There are two antinomic effects: of course the driver no longer has to control the vehicle in AD mode (even though he/she has to monitor the situation in AD L3 and supervise the system in AD L3); therefore the feeling of control (or being able to exert control) is decreasing. On the other hand, the driver feels able to easily take control of the vehicle at any time	In L4, for private cars and public transportation, the feeling of control should disappear even though there can be a driver or supervisor able to take control at any time
Feeling of control of the overall situation (from the perspective of the vehicle user)		
Inappropriate use of automated driving functions	Should increase, despite all barriers designed by manufacturers. Misuse compared to intended use is always possible	
Mental workload (for driving tasks)	Should temporarily increase in L2 driving, and possibly in L3 driving, if the driver has to be attentive in L2 and ready to intervene in L3. Should decrease with experience.	If no more driving, no more workload for driving
Experience of motion sickness	Might increase due to the novelty of AD use	Should decrease since the issue will be taken into consideration after many years of AD use
Interaction with other road users (quality/from failure to perfect)	No clue that L2 systems will increase the overall quality of interactions with other road users, apart from the ODDs	Better quality of interactions, especially in mixed traffic
Feeling of frustration	AD should decrease frustration linked to driving, even in cases where AD-driven vehicles have a lower speed or obey the rules	
Intended use	Inherent to the scenarios. However, in scenario 4, mobility sharing is obviously something rejected by part of the population	
Feeling of pressure because of many parallel tasks	AD is supposed to relieve people, progressively, from driving. Consequently, there will certainly be less competition between driving tasks and other activities in transportation.	

APPENDIX 4: Vienna report

EUCAD2018 SYMPOSIUM

BREAKOUT SESSION REPORT: SOCIO-ECONOMIC IMPACTS

4th April 2018, Vienna

Speakers:	Torsten Geissler, Federal Highway Research Institute (BASt)
	Iain Macbeth, Transport for London
	Kerry Malone, TNO
Moderator:	Satu Innamaa, VTT
Rapporteur:	Salla Kuisma, VTT

DESCRIPTION OF THE BREAKOUT SESSION

Assessing socio-economic impacts and sustainability of automated driving provides valuable insights for drivers/users, fleet operators, transport authorities and road authorities making decisions about investments. To make well-reasoned decisions on future developments, a good understanding is needed of how the benefits for society, sustainability and transport will be reached with increased automation. Furthermore, numerical estimates of benefits need to be provided for the cost-benefit analyses. The focus of the session was on impact mechanisms and the feasibility to assess and estimate impacts for selected impact areas. The use of evaluation results for industry and policy perspectives was also discussed.

The session was divided into three parts. Three speakers gave their insights regarding specific aspects related to socio-economic impacts of automated driving. After every speaker presentation, there was an interactive session where the focus was on engaging the audience to share their views on impacts related to the speaker's topic. In the interactive session, the audience was given three long-term scenarios (Table 1), within which the impacts of automated driving were discussed. The scenarios were formed as part of the CARTRE work into a task for assessing the socio-economic impacts of Connected and Automated Driving (CAD). They are simplified descriptions of reality and were made with the intention to highlight the possible consequences and impacts of alternative decisions. The scenarios will be described in greater detail in a report to be published in September 2018. The impacts discussed were based on the Trilateral Impact Assessment Framework and the Results of the Trilateral Key Performance Indicator (KPI) Survey. In practice, the audience answered twelve poll questions in which they were asked in which of the three scenarios the given impacts would be most likely. The *Slido* tool, which was accessible to the audience via mobile devices, was used in the voting. The audience could also ask questions and give comments by using the tool.

Table 1. Long-term scenarios (2035) for the interactive polls.

	Scenario 1: 'Shared AVs'	Scenario 2: 'Automated PT'	Scenario 3: 'Private AVs'
AV technology	Mature SAE 4 automated vehicles, penetration >50% in mixed traffic		
Use of shared mobility services	High	High	Low
Locus of control	Private	Road authorities; policy driven, private/public collaboration	Private
Basis of transport system	• Market-operated fleets of shared automated cars • Services reliable and convenient • Different level of service with different price • No multimodal services • Regulations and subsidies to ensure minimum level of mobility services to all people	• Demand responsive public transportation for selected routes • Subsidised by public sector • Mainly between major public transport hubs and for lower density areas • Travel chains are well functioning and intermodal • Privately owned automated vehicles quite heavily taxed • Most of the people are used to sharing their mobility and car	• Proliferation of private automated vehicles • People do not respond well to sharing automated vehicles • Owning automated vehicles is affordable for most people • Policies focus on reducing emissions, managing urban space effectively, and increasing safety of automated vehicles

PART 1: MOBILITY, TRAVEL BEHAVIOUR AND THE CITY VIEW ON AUTOMATED DRIVING

THE CITY VIEW ON AUTOMATED DRIVING – IAIN MACBETH, TFL

Cities have an important role in discussing what kind of transport system would be intended in the future and how CAD fits in it. Public authorities are significant users of evaluation results, as policymaking requires knowledge about impacts. Thus, the city view on automated driving is a highly relevant viewpoint regarding socio-economic impacts of CAD. Transport for London (TfL) is a large integrated transport authority responsible for both operating the public transport network and managing London's main roads. Iain Macbeth, Head of Foresight TfL, was invited as a speaker to discuss the city perspective in the session.

Macbeth first gave an introduction on the scale of London transport and TfL. London is growing rapidly, which increases transportation needs continuously. Transportation has a role in unlocking new growth and jobs in cities, but simultaneously the growth puts pressure on the city (Figure 1).

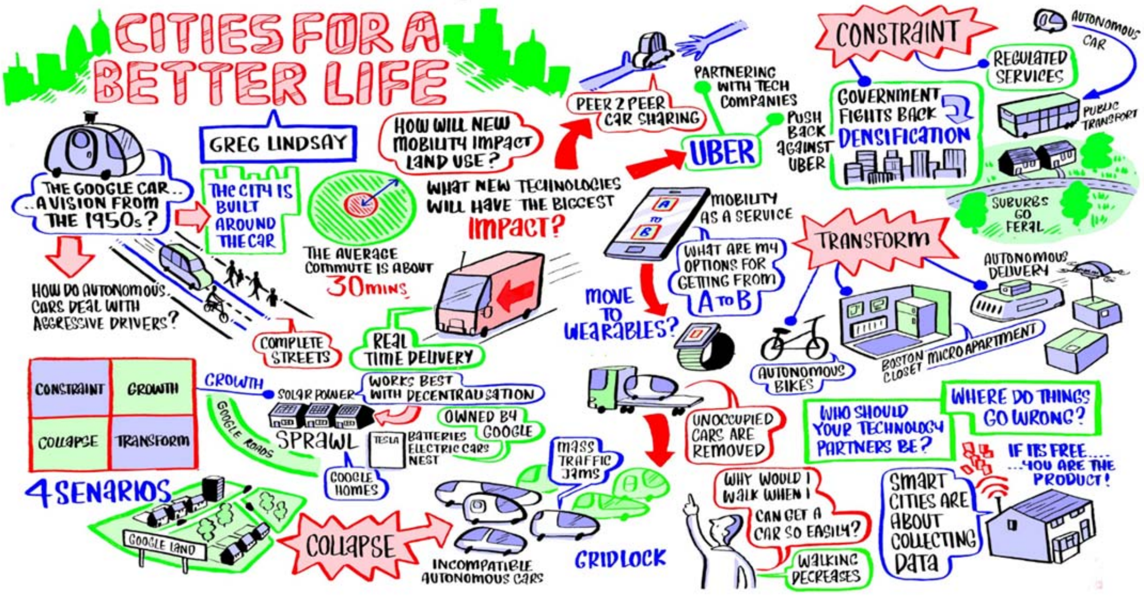

Figure 1. FIA: Cities for a better life.

Macbeth talked about business models and blurring of boundaries of transport actors. According to him, people's relationship with cars is changing. This can be seen, for instance, in an increase in leasing instead of buying. Manufacturers (OEMs) are already assuming that there will be a decline in private car ownership and a rise of shared access. Therefore, OEMs are investing in ridesharing, taxi services and autonomous technology. Macbeth assumes that the next 15–20 years will be a transition period where existing service models will change. We might also need to redefine public transport as traditional actors' roles change.

POLIS, a network of European cities and regions working together to develop innovative technologies and policies for local transport, has recently published a discussion paper on road vehicle automation. Macbeth argued that the POLIS discussion paper encourages more balanced debate on automated vehicles (AVs) by discussing both positive and negative impacts potentially derived from vehicle automation. This kind of societal and city perspective is needed when discussing the future of CAD.

Macbeth discussed different possible outcomes of deployment of AVs. In a spatial perspective, potential positive outcomes include more public space created by a redundancy of parking, which must be put to other functional uses. Potential negative outcomes of AVs are urban sprawl and longer commuting trips. In the social impact area, a potential positive outcome is that AVs enhance transport, providing for persons with limited transport access by reducing the cost of service provision. A negative outcome would be increased social diversion and inequality, with mass transit replaced by less inclusive mobility business models.

In the travel behaviour impact area, positive outcomes could be a reduction in private car ownership in favour of public transport and shared mobility. Possible negative outcomes include more motorized trips to the detriment of active travel and public health. There is a justified concern that travellers using public transport and active travel modes would switch to self-driving cars. Macbeth showed the results from a survey by the Boston Consulting Group, where around 50% of rail passengers and 70% of bus, tram and subway users indicated that they would switch to a self-driving vehicle. Among cyclists, the corresponding figure was around 30%.

When it comes to road safety, AVs could reduce driver distraction and increase road rules compliance. However, the fallibility of technology creates a risk for negative impacts on safety. Traffic management and efficiency through a C-ITS approach could enable richer data for traffic and asset management and improved vehicle control. A possible negative outcome of AVs is that improved traffic efficiency would lead to more vehicles on the road. It is also possible that in the short to medium term there would be “more pain than gain” due to co-existence and higher safety margins. Regarding infrastructure, Macbeth reminded the audience that investments depend on an AV implementation path and that this could mitigate the burden on public funds. If significant investments are required, new business models need to be found.

Macbeth listed key issues for cities and regions. These include policy, planning and urban development, a holistic approach to AVs, personal security and safety, tackling predicted growth in trips and kilometres driven, and managing change. He presented the following recommendations for the future from the POLIS AV discussion paper:

- Keep discussions grounded in reality
- Promote engagement of transportation/road authorities in AV discussions/developments to prepare for and steer their implementation
- Consider how the role and responsibilities of the authority may change with the advent of automation and new mobility services
- Ensure automation developments are not purely industrial policy driven, but also support transport policy and benefit citizens
- Foster partnership and dialogue.

Finally, one conclusion was clear. When cities are planning actions for a better life, there are different scenarios and different possible outcomes. It is important to define what are the intended consequences of changing transport.

QUESTIONS FROM THE AUDIENCE

The audience asked the following questions via the *Slido* tool during the session.

Do you reckon that this change in the mobility patterns – from ownership to car sharing – is going to reduce or increase the number of trips? Do you think that the leisure trips are going to be the first [to] plunge?

Macbeth's answer: This is an interesting question. We already see some changes in leisure trips, and this is probably due to changes in the use of leisure time. There seems to be a trend of staying more indoors with new entertainment services, such as Netflix, and not travelling as much as before. We need to be aware that the changes in trips due to AVs can be hard to distinguish from other changes in society.

How about completely new mobility services already enabled at level 3 or 4 automation (e.g. car-sharing + ride-sharing for peripheral trips with self-empty vehicle relocation)?

Macbeth's answer: I would say that electrification is a relevant issue here, to which also these completely new mobility services are tied. Electrification of self-empty vehicles could lead to electric charging being centralized. This is an also an interesting theme to consider when discussing the new mobility services, as we don't wish to encourage excessive empty running.

Looking at the polls, we need to [have] more shared and public transport. How to motivate the drivers for that? [This question came up after several rounds of the poll voting in the session had been completed.]

Macbeth's answer: There is a whole suite of tools a city can do to enhance public transport. Examples of tools that cities can use are policies that promote active travel and address air quality, and looking into next-generation road user charging and taxation.

Moderator's comment: It seems that this issue is so important that also more research would be needed on motivating people to share.

The audience also raised the following questions related to the topic:

- *How to deal with the mass transit loss issue, can we do something about it?*
- *What role do you see for road tolls on automated vehicles?*
- *There is a major (psychological) difference between vehicle sharing and trip sharing. Take-up of trip sharing is not widespread, although it is the major pillar in our "heaven" AV scenario. How can we make progress with it?*

INTERACTIVE SESSION ON MOBILITY AND TRAVEL BEHAVIOUR IMPACTS

Based on the scenarios introduced earlier (Table 1), the audience was asked to answer four questions on mobility and travel behaviour impacts. In each question, the audience was asked to select the scenario in which the given impact would be most likely to happen. The poll questions and answers are presented in Figures 2, 3, 4 and 5.

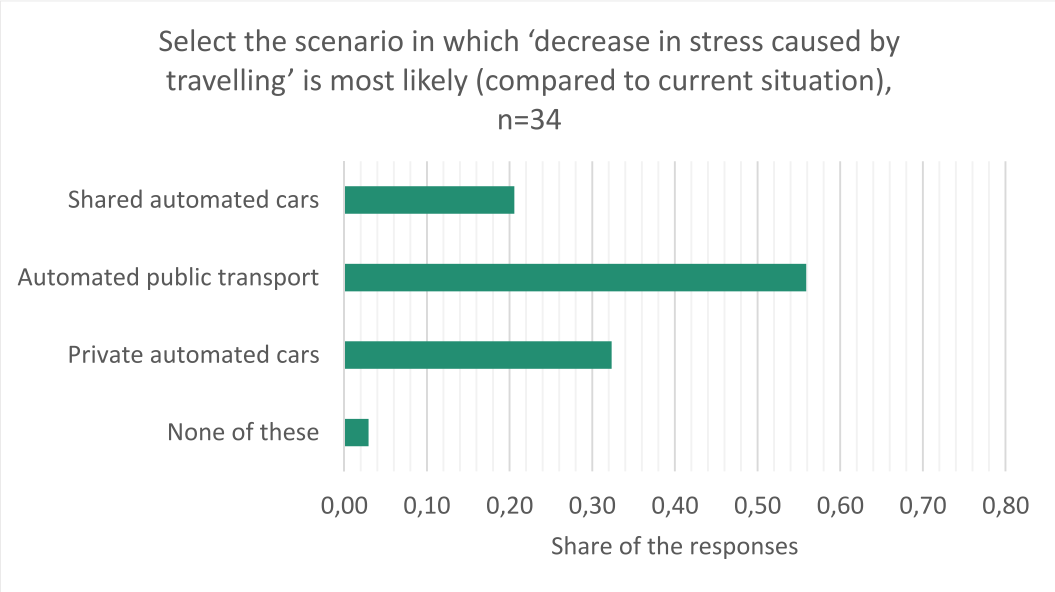

Figure 2. Responses to a question regarding stress caused by travelling.

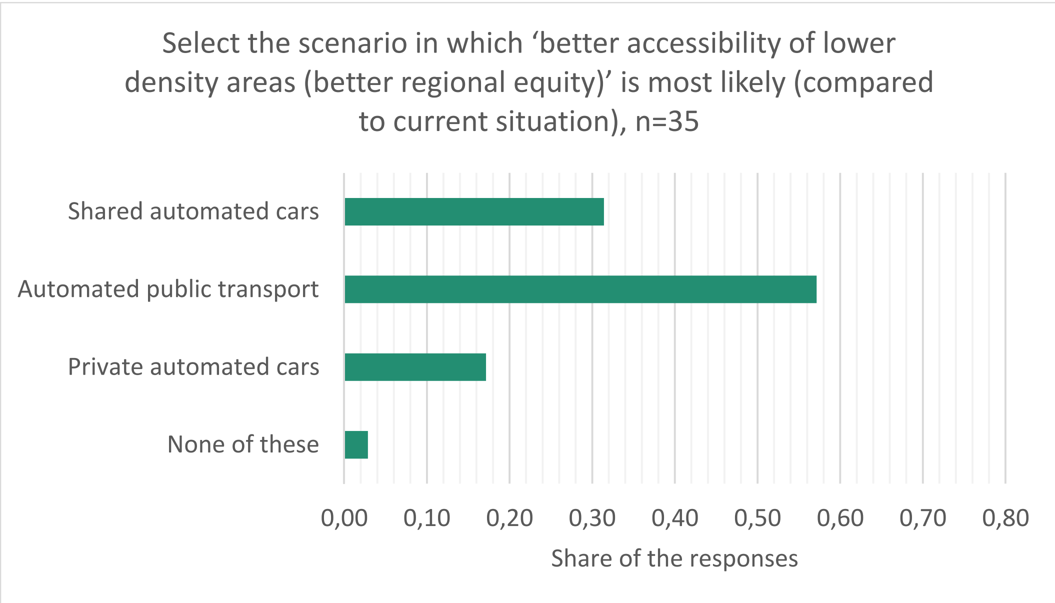

Figure 3. Responses to a question regarding accessibility of lower density areas.

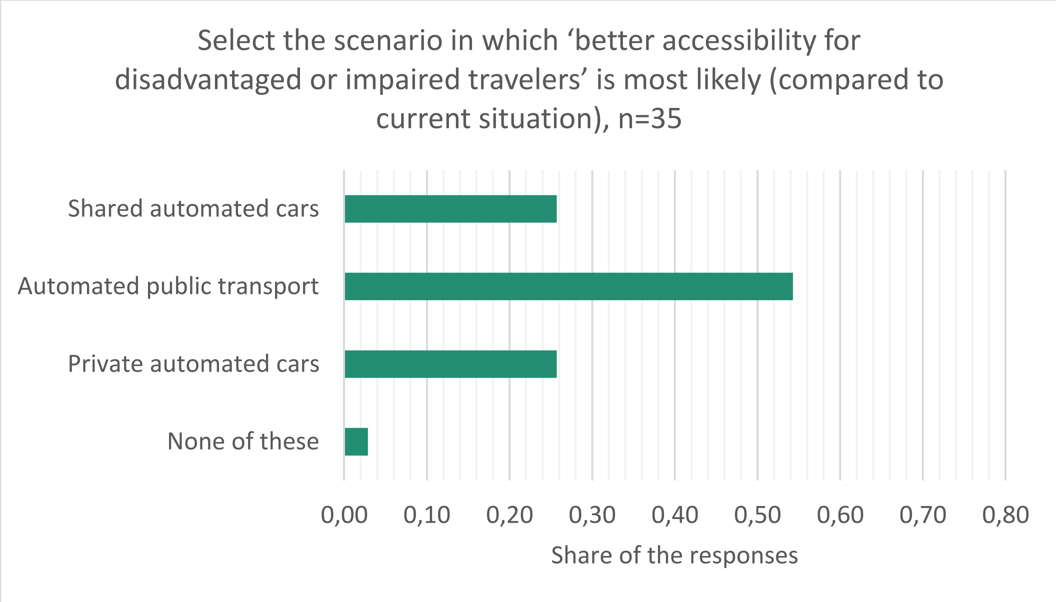

Figure 4. Responses to a question regarding accessibility for disadvantaged or impaired travellers.

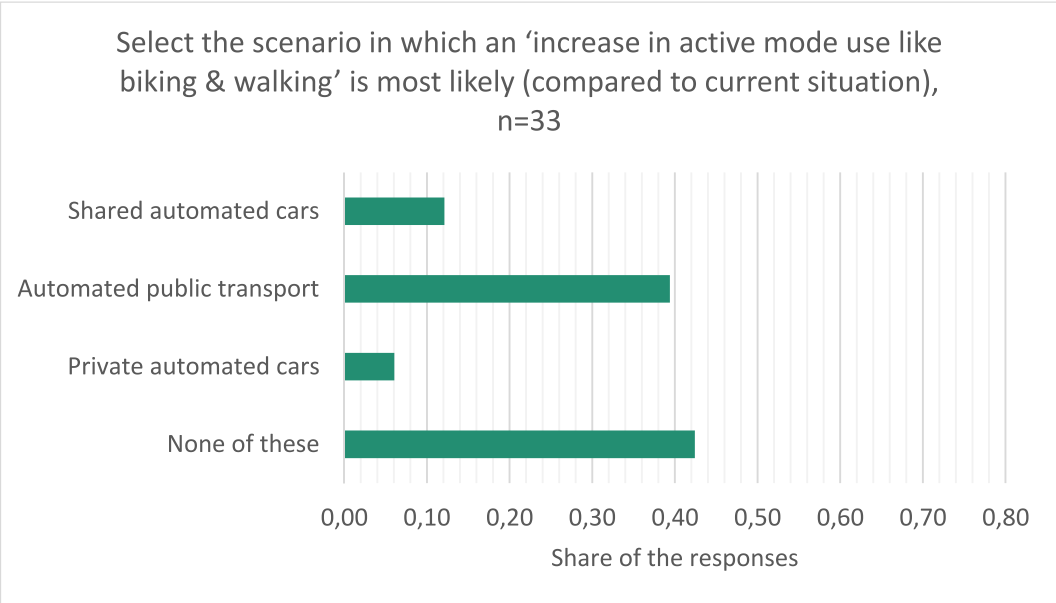

Figure 5. Responses to a question regarding active mode use.

PART 2: TRAFFIC FLOW, CAPACITY AND EFFICIENCY

IMPACTS ON TRAFFIC FLOW AND CAPACITY – KERRY MALONE, TNO

Traffic flow and capacity of roads are relevant issues considering the socio-economic impacts of CAD. Kerry Malone from TNO is experienced in this area and was invited to discuss how AVs can impact traffic flow, on what it depends, and what kind of knowledge is required in assessing the impacts.

Malone began with a short introduction on the different ways in which currently available AVs differ from manually driven vehicles and how they affect traffic flow. AVs do some things differently compared to manually driven vehicles, for example in longitudinal and lateral behaviour. Currently available AVs may need larger headways and gaps, which is not good for capacity. They can also be ‘anti-social’, meaning that they are not helping to create a gap for a vehicle from the next lane to cut into, for instance. They may come across as aggressive (braking late) or quite slow to accelerate. It has been encountered that we do not always know how they will behave differently and when they will behave differently compared to manually driven vehicles. When AVs do unexpected things, other drivers may react in unexpected ways too, which may affect the traffic flow. Malone noted that it has not yet clearly been defined what the definition of driving “well” is in the case of AVs.

On what does how automated vehicles affect traffic flow depend, then? Malone listed four things to start with: the characteristics of the driving behaviour of AVs in relation to 1) Physical and digital infrastructures, including (V2V, V2I) communication, 2) traffic states/conditions (how busy/chaotic), 3) traffic laws and regulations and 4) traffic management measures and/or services (roadside or in-car).

These uncertainties also indicate what we need to observe, measure, describe and simulate. Malone emphasized that especially discontinuities such as lane drops or merging and exiting sections are relevant situations to test or simulate. Highly relevant issues regarding traffic flow and capacity are increasing penetration rates and levels of automation. It needs to be learned when and where AD functions can be and are used by drivers. The expected impact size over time depends on mileage as well.

To figure out how automated vehicles affect traffic flow, we need to understand the current driving behaviour of conventional vehicles, the driving behaviour of AVs, and the interaction between them. Some challenges regarding these were illustrated (Figure 6). Malone said that the impacts we want to get a grip on are vehicle operations/AV (control) operations including acceleration, deceleration, lane keeping, car following, and lane changing and merging into an adjacent lane. According to Malone, the focus of key performance indicators should be on things like:

- Where AD functions can be used and are used, when transfer of control takes place, how long that takes;
- Speed, acceleration, (strong) deceleration, headways;
- Position in lane, gap acceptance, turning indicators, lane changes and jerk.

With information about lane changes in vehicle operations, the impacts on network efficiency can be explored, meaning lane, link and intersection capacity and throughput, as well as travel time and travel time reliability.

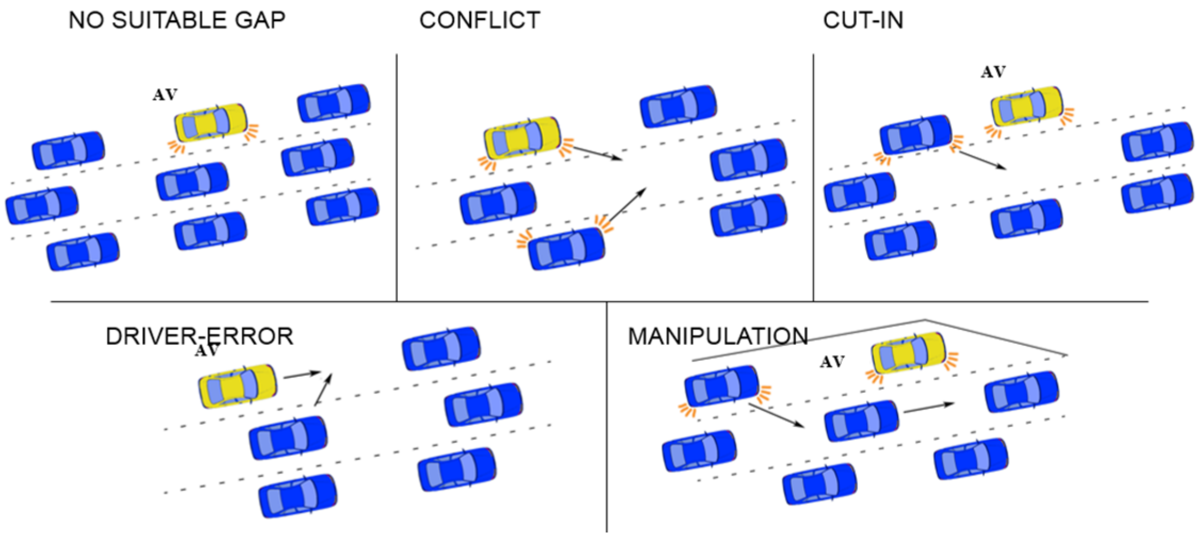

Figure 6. Kerry Malone: Illustration of challenges (TQ MEMO).

Malone's conclusion was that we need to prioritize from where to start the work. Lateral behaviour is the great unknown. According to Malone, we want to increase the ODD while continuing to research challenging situations. The impact on road capacity is an important question, because it is related to huge investment decisions. It is also important for user and stakeholder acceptance. Malone recommended that questions regarding traffic flow and capacity should be incorporated in the set-up of pilots.

QUESTIONS FROM THE AUDIENCE

The audience asked the following questions via the *Slido* tool during the session. Due to limited time, some of the questions were answered during the session and some afterwards.

A recent survey showed that road users were very satisfied with the behaviour of Waymo cars. It seemed every Waymo car responded [to] a traffic situation the same exact way (one brain). This made them very predictable drivers. With your expertise, what did you think of this outcome?

Malone's answer: It is not a surprise to me that predictability of AVs was considered desirable. I think there are two important issues when discussing the desirable behaviour of AVs: would an ordinary human driver have reacted the same way and was it the desired way?

Moderator's comment: The desirable behaviour of AVs might also be different depending on the perspective. Users may have different views of what is desirable than road operators, who are looking at the efficiency of the whole transport system.

Do you have any document/idea/analysis with an estimation of the effect of AVs [on] the capacity of the roads? Do you think it could be increased?

Malone's answer: There are some analyses that have looked at the effects of AVs on road capacity in the form of simulations, but there are also critical issues that need to be addressed in order to answer this question fully.

Estimation of the effect of AVs on road capacity has been done in papers such as

- S. C. Calvert, W. J. Schakel, and J. W. C. van Lint, “Will Automated Vehicles Negatively Impact Traffic Flow?,” Journal of Advanced Transportation, vol. 2017, Article ID 3082781, 17 pages, 2017.
- TRA 2018 papers:
    - Mattas, Konstantinos; Makridis, Michail; Ciuffo, Biagio; Alonso Raposo, Maria; Toledo, Tomer; Thiel, Christian, ”Connected and Automated Vehicles on a freeway scenario. Effect on traffic congestion and network capacity” and
    - Hintermayer, Bernhard; Haberl, Michael; Neuhold, Robert; Fellendorf, Martin; Kerschbaumer, Andreas; Rudigier, Martin; Eichberger, Arno; Rogic, Branko, Effects of Automated driving functions on the track availability of the Austrian motorway network

The results in these papers are for specific road types, e.g. motorways. More situations need to be examined on a wider variety of road configurations in order to address the capacity impacts of AVs, e.g. heavy traffic on road sections with discontinuities such as weaving sections, on and off ramps etc. Also parameter/setting choices of the AVs (e.g. headway, gap acceptance etc., which may vary between different brands) and penetration rates need to be examined.

How would V2V affect these results?

Malone’s answer: V2V would affect the results considerably. The question is why/how?
V2V communication enables communication of e.g. critical parameters for string stability and of information and warnings, as well as negotiation between vehicles (gap creation, optimal speed for the entire traffic flow).

If there is a flow and capacity problem in mixed traffic? Do we need to allocate separate lanes for AVs at some point of fleet penetration?

Malone’s answer: The need for separate lanes is a benefit-cost decision and an equity question. Separate lanes for AVs come either at the expense of existing lane capacity or need to be built, which are costs. Do the benefits justify the costs? And, if space is specifically allocated to AVs, is that from the standpoint of social equity a desired situation?

From our polls we think [we] know that only automated public transport could ease congestion. How can we make sure this will happen and [that] not one of the other scenarios will become reality?

Malone’s answer: This is a policy and cultural question. The emphasis would be on MaaS and Public Transport.

What [do] you think about some elements of centralized control of CAVs (routing, scheduling) to provide better network efficiency?

Malone’s answer: This would be beneficial, but it would require the cooperation of many stakeholders to achieve this. The barriers are high.

What research has there been on the observed (not simulated) effects of current L1 systems (e.g. ACC) on motorway traffic flow?

Malone’s answer: In the Netherlands, the A2 study (ACC, Haskoning / DHV), the EuroFOT study, the Dutch Driving Assistant (“Rijassistent”) pilot. There are probably more regional or national pilots that took place than are mentioned here.

INTERACTIVE SESSION ON EFFICIENCY IMPACTS

Based on the scenarios introduced earlier (Table 1), the audience was asked to answer four questions on efficiency impacts. In each question, the audience was asked to select the scenario in which the given impact would be most likely to happen. The poll questions and answers are presented in Figures 7, 8, 9 and 10.

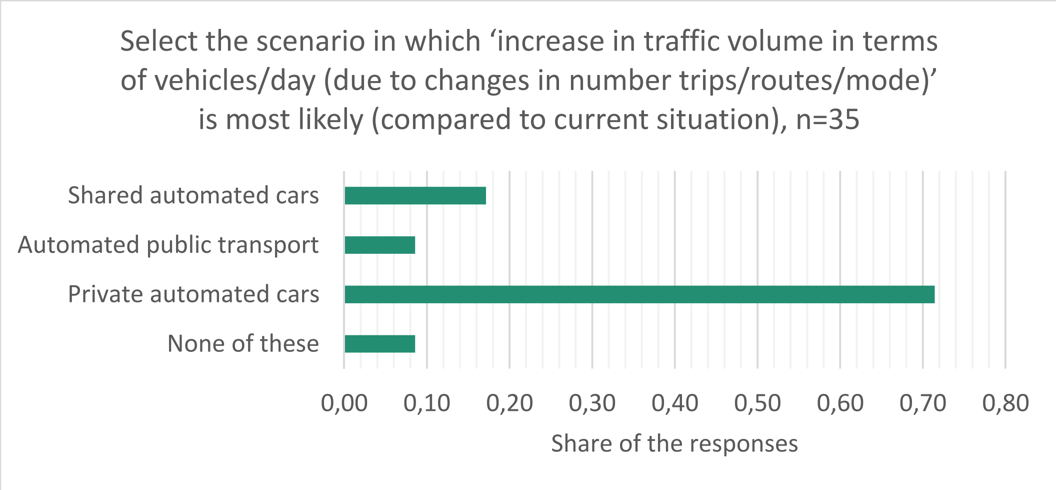

Figure 7. Responses to a question regarding traffic volume.

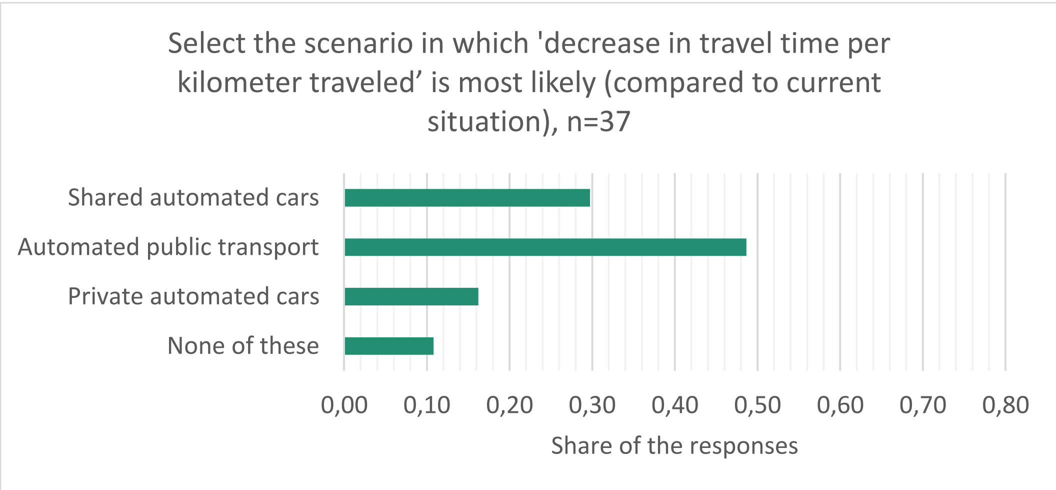

Figure 8. Responses to a question regarding travel time.

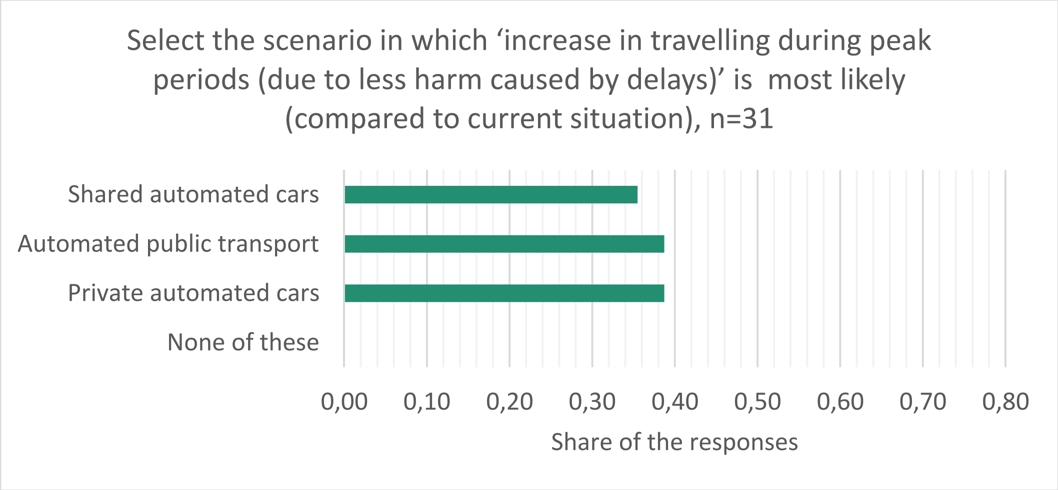

Figure 9. Responses to a question regarding travelling during peak periods.

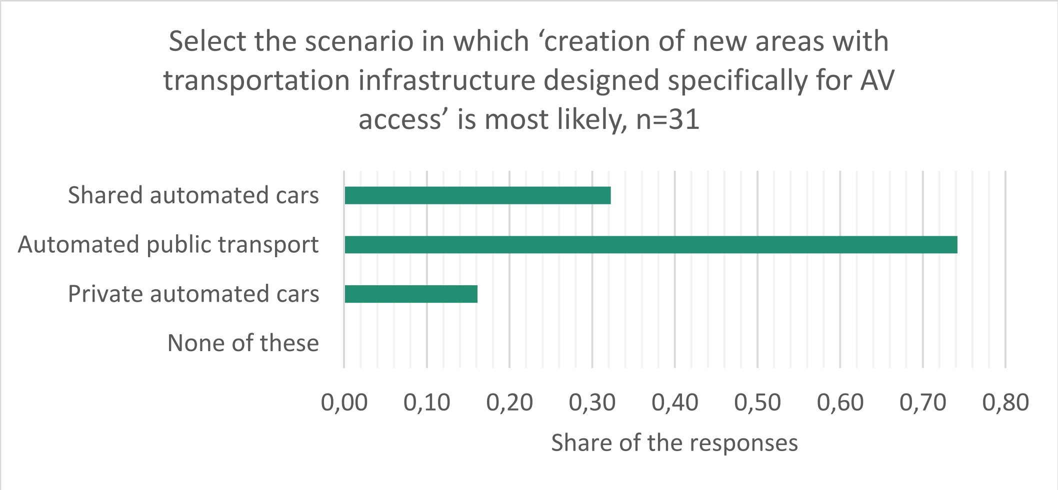

Figure 10. Responses to a question regarding new areas with AV infrastructure.

PART 3: MARKET PENETRATION INFORMATION AND ECONOMIC IMPACTS

MARKET PENETRATION INFORMATION AS ESSENTIAL INPUT TO SOCIO-ECONOMIC IMPACT ASSESSMENT – RECENT EVIDENCE FROM GERMANY – TORSTEN GEISSLER

Penetration information is relevant when assessing different kinds of socio-economic impacts. It was already seen in Kerry Malone's presentation that penetration rates are relevant regarding traffic flow and efficiency impacts of AVs. Torsten Geissler from BASt was invited to talk about market penetration information as an essential input to socio-economic impact assessment. He had recent evidence from Germany to share.

First, market penetration is an essential element for linking macro-level impact and socio-economic impact assessment, typically at macro or aggregated level. Market penetration information is forward looking, more medium- to long-term than short-term. The facilities on which penetration is explored need to be defined, including vehicles and infrastructure, for instance.

Geissler presented bases on which market penetration information can be gained. Historic experiences can be utilized: for example, exhaust gas purification or airbags can be viewed as illustrative cases from the past. Calculation can be made based on assumptions. Calculations and the underlying assumptions can be supported by market penetration survey as the gradually filling data base will enhance information.

In Germany, a comprehensive survey of passenger car equipment with vehicle safety systems (advanced driver assistance systems, lower levels of automation systems) has been conducted three times in the past five years. It is input for the Accident Prevention Report released every two years. The survey gives reliable information on market penetration, allowing for additional insight into market segments and socio-demographic information (mileage, road types etc.) Geissler said that this kind of "downstream" survey provides key value added to other available sources ("upstream"). In the long run, time series on market penetration will support impact assessment and better insight into the slope and gradient of penetration curves.

The latest survey was still under way, and the results Geissler presented were from the last survey conducted in 2015. The survey results from the 2015 wave showed that passive safety was high on penetration ranking, with four out of five systems. Summer/winter tires in exchange, navigation systems and ESC were also widely penetrated. Geissler also showed how different market segments were outlined.

Finally, Geissler described what is coming next in their work. There will be a regrouping of systems with automation levels as a leading ontology and system dependencies illustration. In a longer-term view, the methodology will potentially be revised, meaning revision of survey performance from a systems-to-services perspective, for instance.

QUESTIONS FROM THE AUDIENCE

The audience asked the following questions via the *Slido* tool during the session. Due to limited time, some of the questions were answered during the session and some afterwards.

So far, driver assistance systems do not necessarily depend on technical roadside infrastructure. How does the need for car2x communication influence the assumption of penetration rates for AVs?

Geissler's answer: It is good not to use penetration rates on the vehicle side alone, but also how good the coverage is on communication systems. Some aspects of penetration are easier to measure than others.

Dedicate more investments in connectivity or automation in both [the] short and medium term?

Geissler's answer: Connectivity and automation will go hand-in-hand because they benefit from each other. Investments have to be made (and increased) on both elements, across sectors (private industry, public bodies) in order to co-create the ecosystem around connected and automated driving.

INTERACTIVE SESSION ON ECONOMIC IMPACTS

Based on the scenarios introduced earlier (Table 1), the audience was asked to answer four questions on economic impacts. In each question, the audience was supposed to select the scenario in which the given impact would be most likely to happen. The poll questions and answers are presented in Figures 11, 12, 13 and 14.

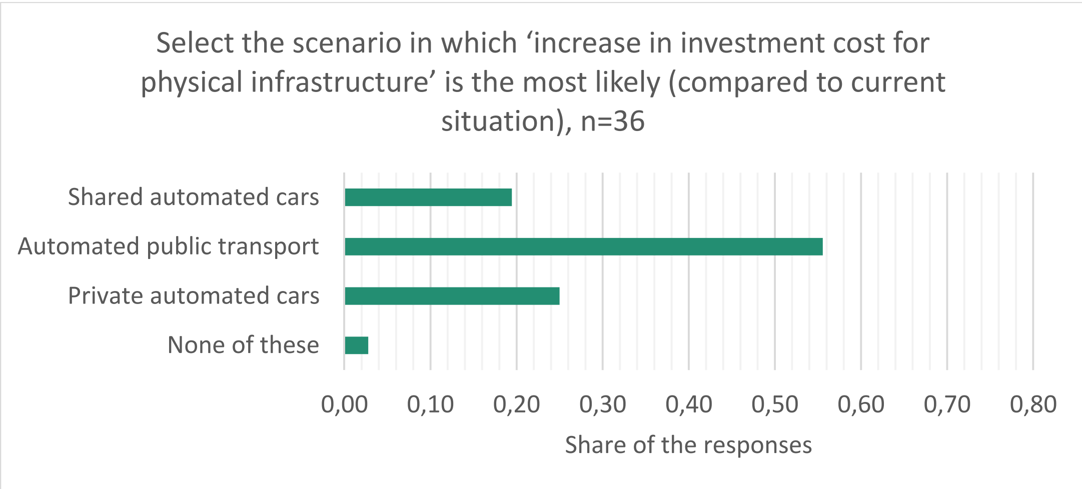

Figure 11. Responses to a question regarding investment costs of physical infrastructure.

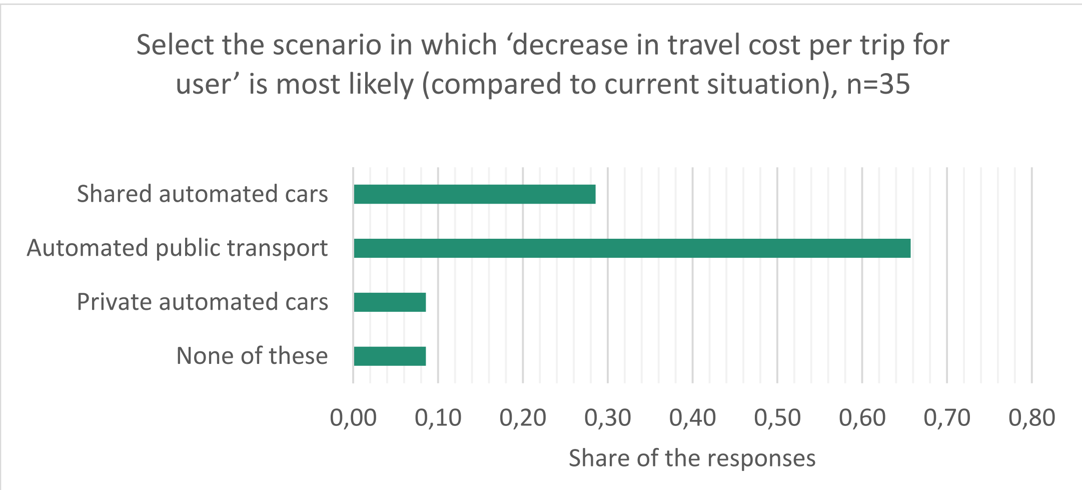

Figure 12. Responses to a question regarding costs for the user.

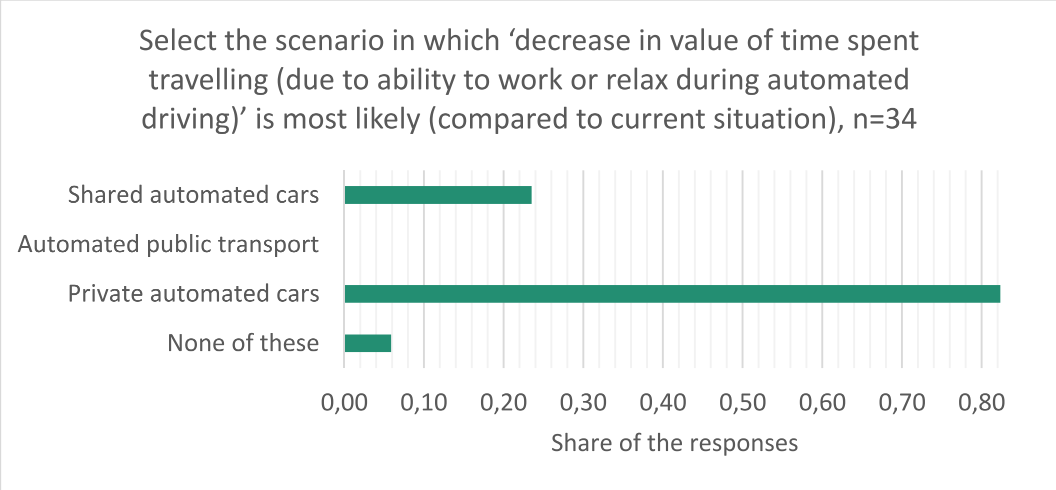

Figure 13. Responses to a question regarding the value of time.

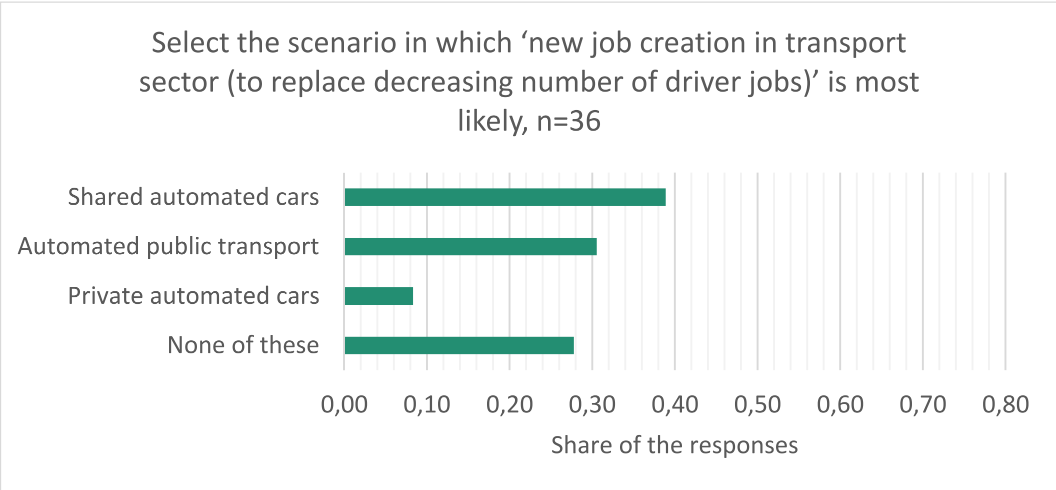

Figure 14. Responses to a question regarding new job creation.

WRAP UP, CONCLUSIONS AND NEXT STEPS

The moderator concluded that based on the session discussions, the current situation (baseline) needs to be known well in order to do the necessary scaling up. However, it seems that besides that, a lot of new input is required for assessing the socio-economic impacts of AVs.

An important question is from where we should start the work. Each of the three speakers gave their insights regarding this question. Macbeth stated that in addition to the role of the authorities, people need to have a good knowledge of the capabilities of vehicles and the systems to avoid accidents. It seems to be common that people are not reading the manuals and they are having high faith in the vehicle. Thus, more information and education for the users is needed. Malone said that we should get experience with the vehicles and not to be too afraid. According to Malone, we need to define what learning outcomes are wanted from the pilots and experiments. Geissler encouraged facing the challenges and possibilities of AVs and the future of transport.

The following conclusions were made based on the presentations, interactive polls and discussion of socio-economic impacts:

- The intended consequences of automation need to be defined, i.e. what the desirable outcomes would be
- The desirable behaviour of AVs needs to be defined (recognizing that for instance the user perspective and efficiency perspective may differ in relation to desirable behaviour)
- The current status needs to be known well (baseline), but it was discussed that also a lot of new input is needed for scaling up
- Policy/authorities-led shared automated mobility could enhance many positive impacts (poll results), but it needs to be discussed how to motivate people to share their mobility.

The following next steps or research needs came up in the session:

- Define the desirable outcome of vehicle automation
- Start testing different concepts of automation in order to learn
- Cooperate with local transport operators to ensure common views on goals and how to achieve them
- Research how to motivate people to share their mobility.