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Assessing societal impacts in future automated driving scenarios - Tentative expert estimates

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Abstract

The study was designed to assess societal impacts of automated driving in four future service scenarios. Experts in automated driving assessed impacts on eight impact areas. Overall, the effects were assessed to be most beneficial in a future scenario highlighting success in shared mobility and the role of public authorities. The assumed changes in driving behaviour would contribute in better road safety but less efficient traffic flow. Some negative effects in mobility were associated in three of the four future scenarios, mostly in a scenario highlighting use of private automated cars. Some costs were expected already in the short term with increase in travel comfort. Besides describing potential impacts in different development paths, the paper provides an initial assessment of the factors affecting them. All results are tentative estimates that should be verified in further empirical studies.

Keywords:

Automated driving, impacts, societal

Introduction

Developing a highly automated transport system calls for decisions of substantial investments both by industry and by public road authorities. Furthermore, the life cycles of investments in the road transport system are long, and the decisions made today have far-reaching consequences in the future. Well-reasoned decisions should be built on a solid knowledge base about the impacts of the planned measures (on side of data on costs, payers, winners etc.). The social impacts of automation are, however, largely unknown.

The new technology solutions are pushing the development; implementation is reasoned by previous knowledge, expert opinions and common sense. Research activities in big scale are going on but the results of the automated driving pilots are expected not sooner than in a couple of years. It is noted that some relevant literature on impacts is available [1], and user acceptance has been a topic in several studies [2, 3]. However, the evidence is still limited. Experts in the area are having lively discussions and debate about the future; how it will look like, how the key political targets are going to be reached in an automated transport system. All this motivates to provide ex ante expert assessments about the impacts, even if these would be made with reservation and acknowledging the qualitative nature of the estimates and uncertainties related to them.

In an ex ante evaluation, future scenarios are created to describe the service and the circumstances in which the measure is thought to be applied. Scenarios are simplified descriptions of reality, each picturing a possible future world, and are made with the intention to highlight the possible consequences and impacts of selected alternative decisions. Based on two recent scenario-based studies on automated driving [4, 5], the 'role of road authorities' (ambitious and proactive vs. slow and careful) and 'service development' (role of shared solutions) were selected as key variables in this study. The perspective of cities and regions has been further exposed in the discussion paper of POLIS [6] on road vehicle automation. Regarding automated driving functions, the European Technology Platform ERTRAC indicated which automated driving services are expected to be available in the selected target years: the passenger car, the freight vehicle and the urban mobility vehicles path [7].

The EU support action CARTRE networked European experts in the area of automated driving. The participants of this CARTRE task represented industry, research and road authorities. They were called to discuss and assess the potential societal impacts of automation in a structured approach. The study utilized the work of the Trilateral Working Group on Automation in Road Transportation (Trilateral ART WG) [8] – Impact areas identified in that group and key performance indicators (KPIs) suggested [9], in particular.

The goal of the study was to provide tentative and qualitative impact estimates of automated driving for the selected future scenarios and impact areas. Furthermore, the group modified the KPIs, suggested new KPIs, discussed which impacts would be beneficial and provided lists of factors increasing or decreasing the intended benefits.

Approach and evaluation procedure

Altogether eight impact areas were addressed: (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, (8) Economic analysis.

Automated driving service -based estimation

In the analysis of three impact areas ('Driver behaviour', 'Network efficiency' and 'Energy and environment'), a more detailed description of automated driving (AD) services was found to be necessary. The estimates were, in the first phase, made service by service. The five services determined were: Highway autopilot including highway convoy; Urban & suburban pilot; Automated valet parking; Privately operated, automated personal rapid transit (PRT)/shuttles in mixed traffic; Publicly operated, automated buses and trams in mixed traffic.

It is worth noting that the services addressed 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'[1]. The calculations resulted in quite small fleet penetrations. The differences between the future scenarios were experienced as small on driver behaviour and in traffic flow due to assumed small fleet penetration and therefore, the comparisons between the scenarios were less in focus for these impact areas.

Scenario-based estimation

The impacts interact with each other in various and complex ways. Therefore, we chose scenario-based assessment for most impact areas to handle these dependencies of the societal impacts at least to some degree (Figure 1). Four scenarios, shortly introduced here, were described to create context for the assessment. In the evaluation process, experts involved gave their insights on the impacts of automated driving in each scenario.

Scenario 1: Gradual extrapolation of automated services

The time perspective of this short-term scenario was roughly up to 2025. 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 ACC Stop & Go assist. SAE L3 level functions have been introduced including traffic jam chauffeur, highway chauffeur and automated urban bus chauffeur [7,10], 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 was assumed in scenario 1 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. However, as system penetrations are still small, automated functions cannot be built on the assumption of connectivity.

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. In some cities, and in some urban areas (not yet widely in Europe), automated buses are operating on dedicated roads or areas. The public sector has been supportive towards the development of automated vehicles and testing, as well as new mobility services. The EC (and global organizations) is implementing regulation to enable and support implementation of C-ITS and automation.

Scenario 2: Market-operated fleets of shared automated vehicles

In the long-term scenarios (approximately to year 2035) SAE L4 functions are in use including highway autopilot, urban and suburban pilot, and automated shuttles and buses in mixed traffic. The

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[1] The results of the ecoDriver EU-project (2011–2016, http://www.ecodriver-project.eu) were utilized in the estimates of vehicle kms in different road types.

freight vehicles path includes SAE L4 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 was assumed to be roughly 50%. In fact, it showed out that this was an optimistic estimate for the targeted period, and the fleet penetrations could be much lower. In spite of this, the scenario based assessment assumed a considerable fleet penetration (close to the original 50%). SAE L4 functions were assumed to be more mature and more in use on highways (and parking) than in urban mixed traffic.

Shared mobility services have broken through and become mainstream. Fleets of shared and automated vehicles are market operated. Operators are competing against each other for customers, and different levels of service are available. The 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. 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. New services and business models of public transport are emerging. An increase of driverless buses is reducing the costs of bus travel.

Scenario 3: Authority-driven shared automated transportation

The target year and automated driving technology was same as in scenario 2. In this scenario, there was a service of driverless vehicles providing demand-responsive public transportation for selected routes. There has been a proliferation of commercially explored automated public transportation systems. 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.

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.

Scenario 4: Proliferation of private automated vehicles

The target year and automated driving technology was same as in scenario 2. People have not responded well to sharing automated vehicles with strangers without a driver present. Owning automated vehicles is affordable for most people.

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.

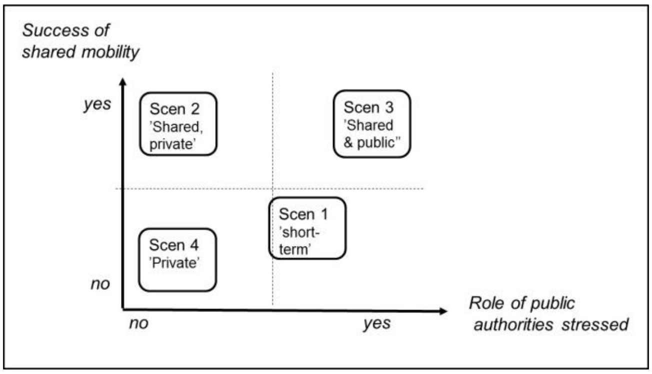


Figure 1 - Schematic picture of assessment scenarios. Scenarios 2, 3 and 4 are long-term scenarios

Evaluation procedure

Seventeen experts from thirteen organizations shared responsibilities in the study and provided independent impact estimates for the selected impact areas.

The experts were organized in three groups and two to three impact areas were assigned for each group. Firstly, the groups sketch impacts and impact mechanisms to create an overall picture. Next, a suitable list of KPIs for each impact area was discussed and determined. Also the beneficial/targeted direction of change in each KPI was valued from the societal perspective.

The experts 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 or five services. In the scenario-based assessment, the values were relative in nature enabling comparison of estimated impacts between the scenarios. For the three service based assessment (e.g. driver behaviour) a scale from 1 to 5 was defined as numerical estimates indicating also the size of expected impact.

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 create a consensus of the group on the impacts for each KPI regarding the magnitude of the change and uncertainty of the assessment. In addition, the experts were asked to write down descriptions of the factors influencing the effects and other reasoning behind their estimates.

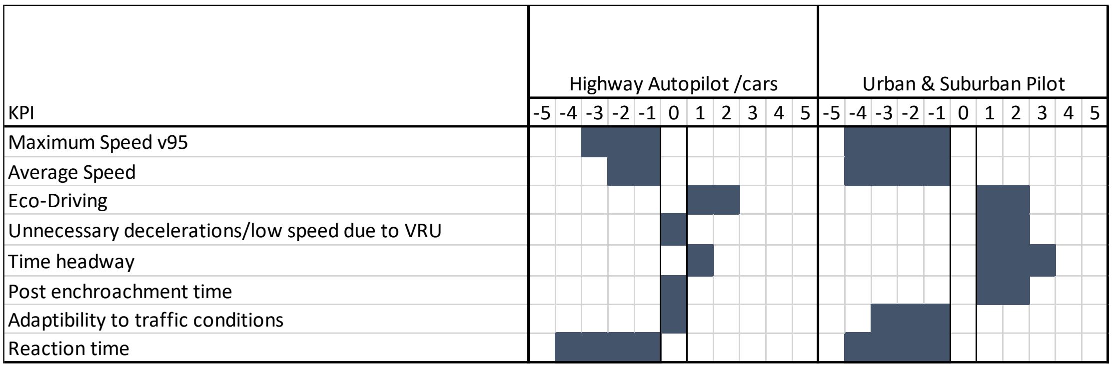
Results

Effects of automated driving services on driver behaviour, network efficiency and environment

In the analysis of three impact areas, driver behaviour, energy and environment and network efficiency, impacts were assessed by automated driving services before proceeding with scenario-based assessment. The changes in driver behaviour (driving behaviour of the automated vehicle) are critical, as many societal impacts are built on it.

Two service paths are in focus for car driving: the Highway Autopilot and the Urban/Sub-urban Autopilot (Figure 2). Generally, automated driving was seen to decrease speed (maximum speed and average speed), increase eco-friendly driving style and shorten reaction times. These changes can result in positive societal impacts, considering traffic safety and environment aspects. However, time headway was assumed to increase, as well as unnecessary decelerations/low speed due to interaction with vulnerable road users. Although the group of experts did not expect remarkable changes to road capacity (apart from privately operated, automated Personal Rapid Transit service in mixed traffic, which was assessed to decrease road capacity), travel time per road-km was assessed to increase slightly in case of most automated services.

Adaptability to traffic conditions is likely to be different for different automated driving services. For example, automated driving on highways is expected to have a better adaptability than automated driving in urban environments.



	Highway Autopilot /cars											Urban & Suburban Pilot										
KPI	-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/low speed due to VRU						■												■	■			
Time headway							■											■	■	■		
Post enchroachment time						■												■	■			
Adaptibility to traffic conditions						■								■	■	■						
Reaction time		■	■	■	■								■	■	■	■						

Figure 2 - Impacts of Highway Autopilot and Urban/suburban Pilot on driver behaviour (interval scale: 0 for no effect, 1 for small effect, 5 for large effect).

Many of the discussed KPIs were seen dependent on driving styles of automated vehicles, referring especially to more defensive or conservative driving style, which would lower speeds. Also specifics of the ODD and vehicles' capabilities in predicting humans, are examples of the factors that were considered important. Penetration rates of automated driving services was found a crucial factor, which was also seen in some differences when comparing the effects between the future scenarios.

Societal impacts of automated driving in four scenarios

In this chapter, the focus is on use and acceptance, travel behaviour and mobility, public health and safety, land use and economic costs and benefits, assessed in four alternative future scenarios (Figure 3). Looking at the different impact areas, it appears that user acceptance was assessed overall to be quite high in all of the four scenarios; the experts thought that automated driving would be accepted well and widely used. The high acceptance of automated driving was assessed to be more certain in scenario 3, where the automation is led by authorities and utilised in public transportation. Use and acceptance of automation was seen highly dependent on many factors, such as automated driving functions' perceived performance, reliability and safety.

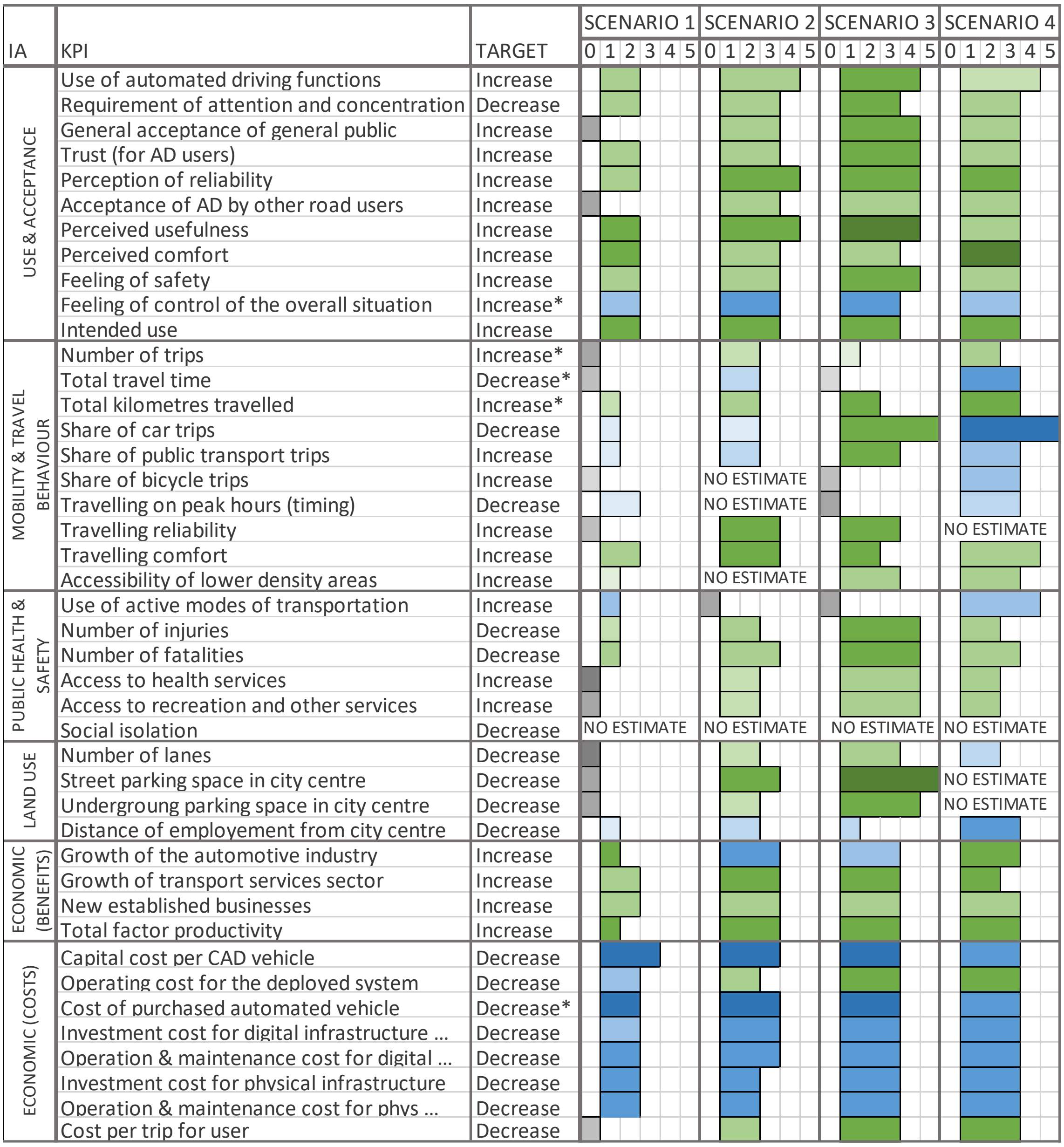


Figure 3 - Estimates of impacts for five impact areas (0=no change, 5=large change; Green for positive and blue for negative change, grey for no change; light for big uncertainty, dark for small uncertainty).

For mobility impacts, the scenarios differed greatly from each other. Scenario 2 (Market-operated fleets of shared vehicles) showed small impacts that were more on beneficial than negative side. Scenario 3 (authority-driven and shared) showed substantial benefits to mobility and scenario 4 (private vehicles) showed some clearly negative effects. Scenario 4, being assessed to have many negative impacts on mobility, was assessed to have positive impacts on accessibility and comfort. In the short term (scenario 1), the effects were minor or none. 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. The pattern regarding land use was quite similar to that of mobility indicating some negative effects in scenario 4. Examples of factors that were identified to affect changes in mobility include personal mobility needs, travel comfort, availability of and preferences for different modes and value of time (also value of travel time while using automated driving). These factors, among others, affect travel behaviour and decisions on amount of travel, travel patterns and quality of travel.

For public health and safety, scenario 3 (authority-driven and shared) showed most benefits. There were not many differences between scenario 2 (shared mobility) and 4 (private cars). Use of active modes (walking and bicycling) was assumed to decrease substantially 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.

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). Scenario 4 (private vehicles) showed more positive impacts on growth of automotive industry, whereas scenarios 2 and 3 showed positive economic impacts on transport services sector. The impacts depend on passengers' interest to use personal and public mobility services as well as incentives from authorities.

Discussion

In this study, a scenario-based expert assessment of the impacts of automated driving was made, providing insight into what the impacts could be in the selected scenarios and for selected automated driving services. The study described potential development paths, and provided an initial assessment of the impacts and the factors affecting them. All results are tentative estimates that should be verified in further empirical studies.

For assessing driver behaviour, (as well as network and environmental impacts), automation services were specified quite detailed. Automated driving penetration in traffic flow was assessed separately taking into account the ODDs, vehicle mileages in ODD and usage, thereby ending up with significantly smaller fleet penetration. Still in long term, substantial potential effects on driver behaviour were estimated – specifically maximum speed (v95), average speed, driving distances (in urban and sub-urban autopilot) and reaction times (in all services), which would lead to positive safety impacts.

The scenarios defined the maturity and use of automation technologies, but also some additional variables were determined. 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 dimensions were taken from recent scenario studies in Sweden and the Netherlands. 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.

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.

In the long term, more substantial impacts were assessed to occur in the three scenarios. 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. Scenario 4 (private vehicles) was assessed quite negative for mobility and travel behaviour KPIs but to be most beneficial for economic growth. 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. Even trust was assessed positively, although it has been identified repeatedly in discussions as a potential obstacle to the acceptance and use of AD [11].

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. Regarding the lists of KPIs, the conclusion is that they 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.

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 experts formed three groups that acted quite independently of each other, but with the same introduction and instructions. The work was organized in sequential phases of individual work followed by discussion and reflection in the group and aiming to a consensus. Thus its nature is subjective - an expert opinion balanced by mutual discussion. The nature of the work implies that several assumptions were made and reported regarding the estimates, the services, the maturity of technology, automation penetration, etc. Therefore, much research is needed to validate the results and get more reliable and accurate estimates. The tentative nature of the results is highlighted. The focus of the work was on comparing the effects, not in providing absolute estimates.

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