EU EIP Activity 4: Harmonisation Cluster

Sub-activity 4.2: Facilitating automated driving

Summary of Impacts, Benefits and Costs of Highly Automated Driving

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Preface

The work for this report is carried out within EU EIP Activity 4.2, Task 2: *Impacts and economic feasibility of automated driving* aiming to identify and discuss the likely direct and indirect impacts of automated driving on mobility, traffic and the operations of road authorities and operators.

The work within this task was divided into three phases where this report constitutes the third and final phase. The phases are:

- Phase one: Methodology and templates, initial desktop analysis.
- Phase two: Project inventory and selection of projects for a structured analysis on impacts.
- Phase three: Selection of projects for analysis and execution of a workshop on Impacts, Costs and Benefits.

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1. Introduction

The work for this report is carried out within EU EIP Activity 4.2, Task 2: *Impacts and economic feasibility of automated driving* aiming to identify and discuss the likely direct and indirect impacts of automated driving on mobility, traffic and the operations of road authorities and operators (new expertise required, quality of services need to be changed, adapted maintenance of roads and especially pavements, etc.).

The report is one part of EU EIP Activity 4.2 which aims to provide guiding documents, supporting road authorities and operators to make decisions on facilitating automated driving and automating their own core business. This is done by identifying the requirements of higher level (SAE 3-5) of automated driving to road authorities/operators; assessing the direct and indirect impacts of higher level automated driving on traffic, mobility and the core business of road authorities and operators; discussing the socio-economic benefits and costs of automated driving from the road operator viewpoint; providing a road map and action plan for especially road operators to facilitate automated driving and providing good practices and lessons learnt in automating road side and traffic centre operations and systems, and a first estimate of the optimal automation levels for such.

The final version of the report hence presents impacts, benefits and costs related to automated driving in context of road operators. A comprehensive literature study was carried out focusing on recent relevant deliverables from the likes of ERTRAC, CARTRE, ARCADE, MANTRA etc. A workshop with experts from Road operators and OEMs' helped to further discuss and reflect the findings from literature studies. While there are many studies made (and ongoing) about impacts and costs of automated driving, it is asked to consider the results with some caution as most of the studies rely on micro and macro simulations to derive an output and that the future reality may or may not match what the studies reflect. Also, there are many other factors such as policies, adoption of automated vehicles or technological solutions that influence if automated driving is enabled at optimal efficiency.

The report also presents some recommendations for the automated driving ecosystem. Recommendations around need to promote pilots, need of infrastructure, data sharing and need of stakeholders pushing each other to progress together.

1.1. Scratching the surface: The four megatrends in mobility

There are, in the views of automotive experts (Kaas, 2016), four major forces of disruption happening, and the unique thing is that they're happening in a simultaneous fashion. The first of the megatrends is electrification of vehicles, it is not a new but still-relevant force of disruption in terms of a more efficient, environmentally sustainable power train.

Number two is connectivity or digitization. Wireless technology enables information to be transferred between different constituencies, it could be a car, a third party, could be between two cars, etc, and this obviously opens up very new technological and operational opportunities and possibilities.

Third, it is about what we call advanced driver-assistance systems, leading the pathway towards automated vehicles.

Last but not least is mobility. There are many more diverse forms of mobility. In other words, how do we get from A to B? The first three technological forces could accelerate mobility, and the adoption of diverse forms of mobility, but they're not necessarily needed to actually push new mobility forms. That is very important to note, to understand those inter-relationships.

A tool developed by McKinsey (McKinsey & Company, 2017) reveals significant investment activities in new mobility technologies—nearly $111 billion in disclosed transactions since 2010 in more than 1,000 companies across ten technology clusters (see figure 1). It can be understood from the figure that, less than a third of these relate to shared-mobility companies; the rest focus on the trends of automation and connectivity. However, one can learn much more from these smaller investments because they are related to smaller companies with special capabilities or technologies. The large transactions, on the other hand, tend to be industry-shaping moves made on established companies. Understanding small players and start-ups is crucial to efficient technology sourcing (McKinsey & Company, 2017).

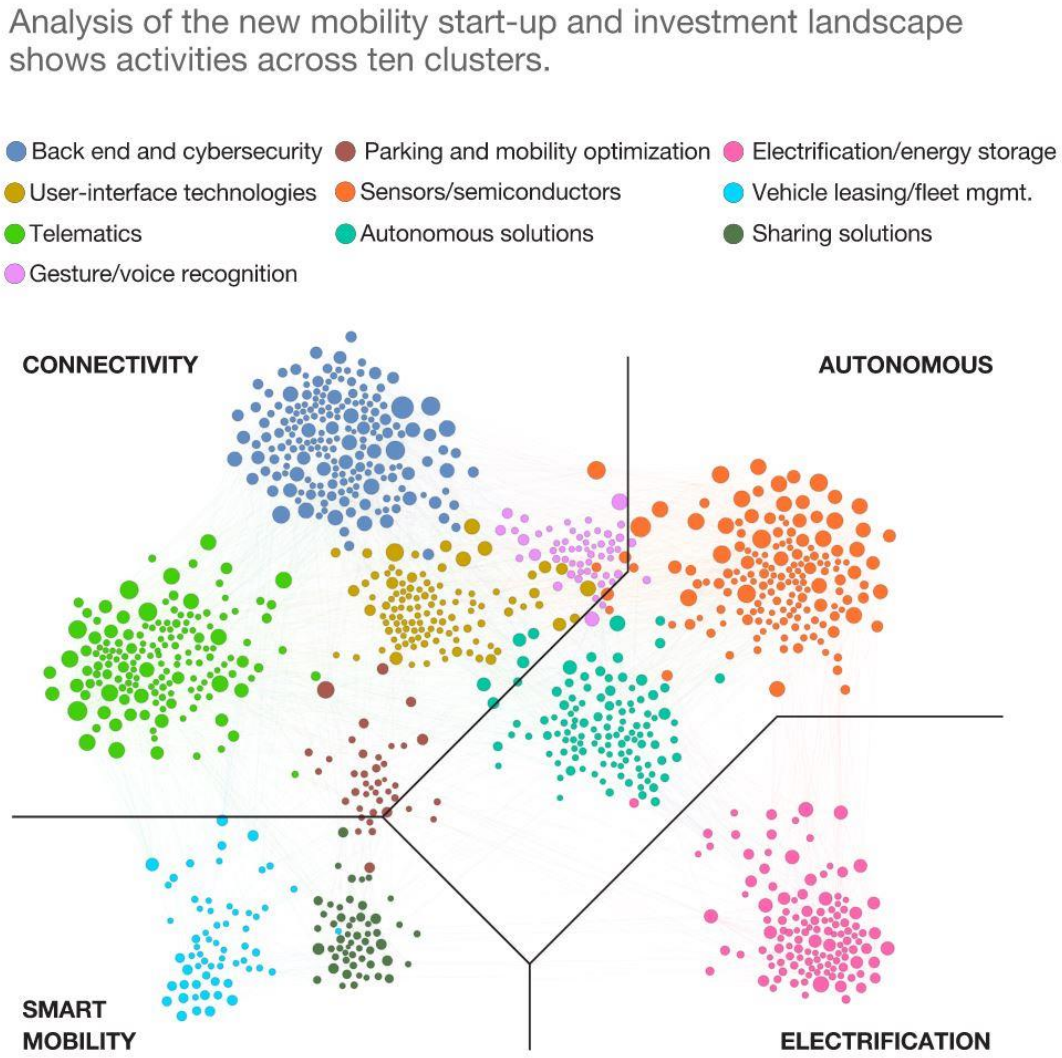

Figure 1: Analysis of the new mobility start-up and investment landscape. (McKinsey & Company, 2017)

If we reflect on what vehicle manufacturers are doing today, on the one hand you see the spectrum of manufacturers who are cautiously exploring their own way. They sometimes mentioned it as experiments or pilots, to see which of those future mobility forms might be willingly adopted by consumers. On the other hand, vehicle manufacturers are making investments, both into equity and into partnerships. (Kaas, 2016) suggests that they should rather do a combination of both the ends to openly explore future businesses.

Today, we see a full spectrum of engagement not only by carmakers but also technological players like Google and Apple, or mobility providers like Lyft or Uber. They are also reaching out to the incumbents to understand what type of domain knowledge in the auto industry is critical to actually define an offer of viable product and/or service.

European Automobile Manufacturers' Association (ACEA) have now released their updated version of roadmap for the deployment of automated driving (see figure 2) which provides a check-list for policy makers and details the legislative framework that must be put in place at the international, EU and national level. Moreover, it contains a timeline setting out the next steps that must be undertaken over the coming years in order to enable the deployment of automated vehicles on Europe's roads in the near future (European Automobile Manufacturers Association (ACEA), 2019).

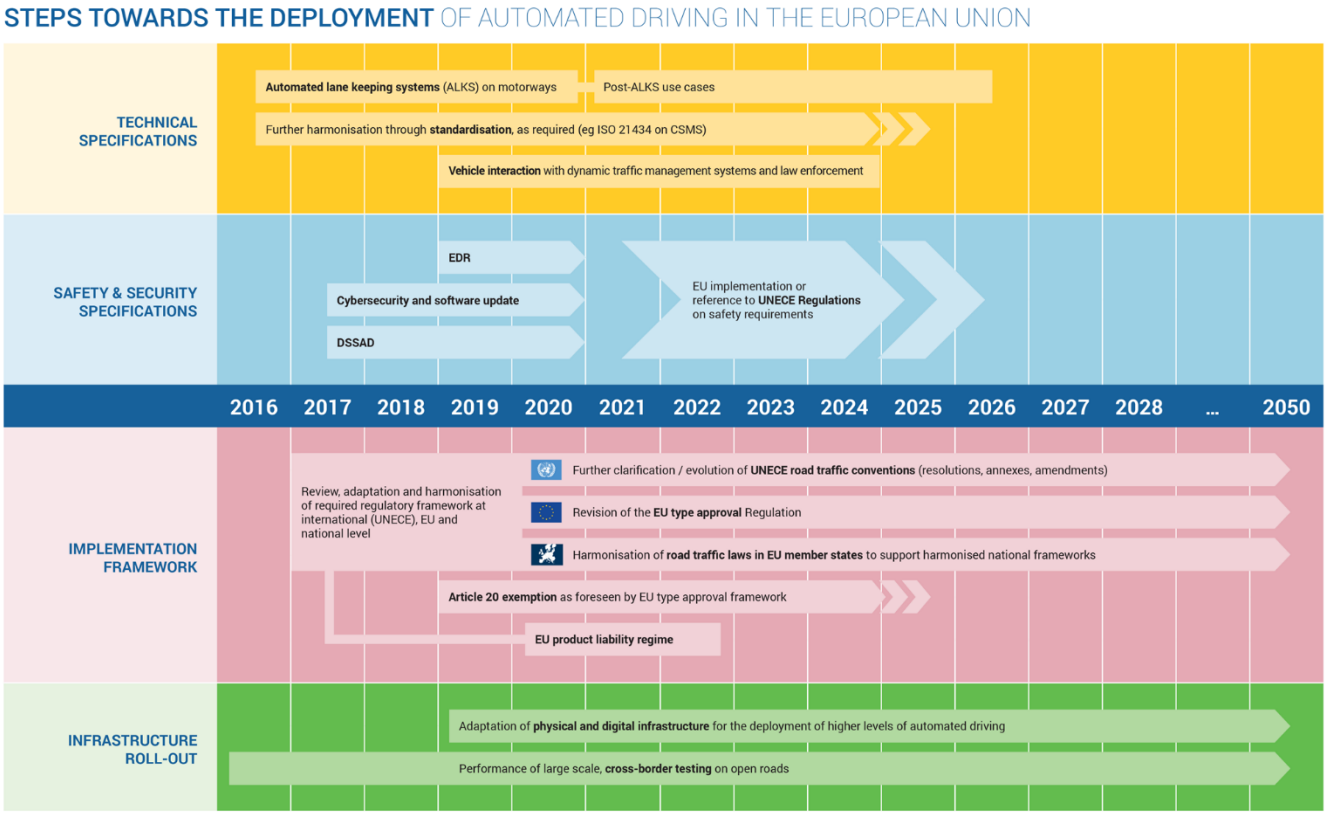

Figure 2: Roadmap for deployment of automated driving (European Automobile Manufacturers Association (ACEA), 2019)

1.2. AV technologies and their implications

As an end-user product, the 20th century motorcar changed the ways that cities worked, how people moved about and interacted, and how goods and services were transported. To facilitate these changes, governments adopted policies, regulations and investments that – for example – assigned road primacy to motor vehicles, expanded the road network, addressed traffic circulation.

Information and Communications Technologies (ICT) have played a growing role in human-driven cars for the control and management of core vehicle functions, driver assistance, and external communications. Nevertheless, the human driver and traditional motor vehicle engineering have remained dominant. This is about to change dramatically, and with significant potential implications for urban policies and investments. (Ticoll, 2015)

Certain ICTs – for example, a dashboard animation of traffic-efficient routing – will be part of the "end user" automated vehicle (AV) experience. Less visible underlying applications – such as (V2X) communications – will support conditions for safety and optimized traffic. To achieve the full potential of AVs and their benefits, cities will have to implement policies, programs and infrastructures towards end user functions, underlying technology capabilities, energy efficiency – and broader social, urban planning and fiscal objectives.

An automated vehicle is essentially a type of robot – a machine that can sense its environment, assess and plan what to do, act on that plan, and communicate with people

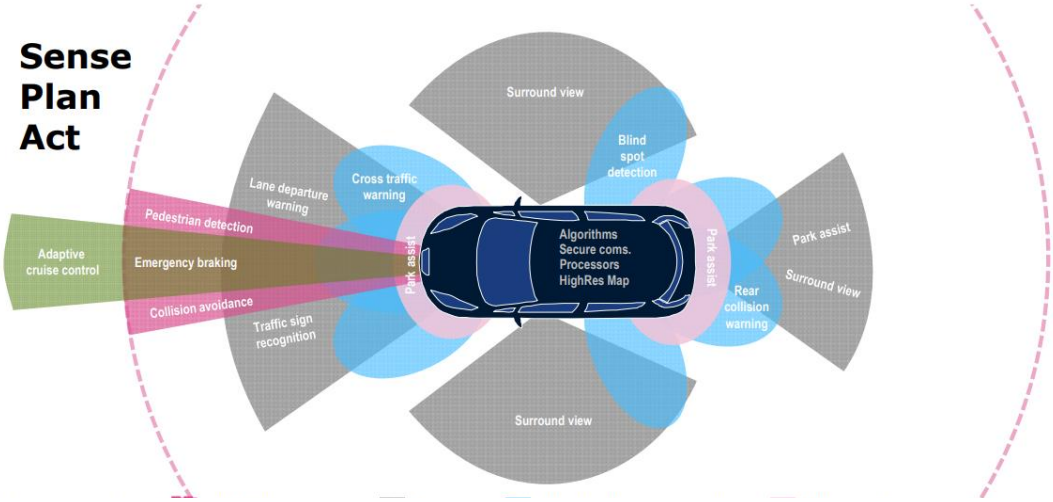

Figure 3: Depiction of various sensors on an automated connected vehicle (OECD Corporate Partnership Board, 2015)

and other devices. In every AV, each of these activities requires a set of innovative physical technologies, massive data resources, advanced algorithms, and blazing processing speeds.

Technologies allow vehicles to sense the dynamic driving environment (OECD Corporate Partnership Board, 2015). Sensing alone entails a vast array of views, activities and technologies, many of which are illustrated in Figure 3 and Figure 4.

In addition to these, an AV may exchange digital communications with traffic management infrastructures (V2I), other vehicles (V2V), pedestrians (V2P), cyclists and so on, using active sensors.

After “sensing”, the next phase is to organize and assess what the vehicle’s sensors have “seen”, heard, or received, compare it with the passenger-assigned destination, and plan the trip’s next moves – continually and in fractions of a second. This is the most challenging and critical task of an AV’s automated system. Conceptually, there are two possible approaches to this task. A brute force method is for a vehicle to look around itself and assess everything that is going on, almost from scratch. It can consult a generic application like Google Maps, but it must look out for speed bumps and potholes, curb heights, temporary road construction, pedestrians, other vehicles, and so on. This is technologically inefficient (requiring significant in-vehicle sensing and processing power) and risky (as some road features may be hidden or hard to read). (Ticoll, 2015)

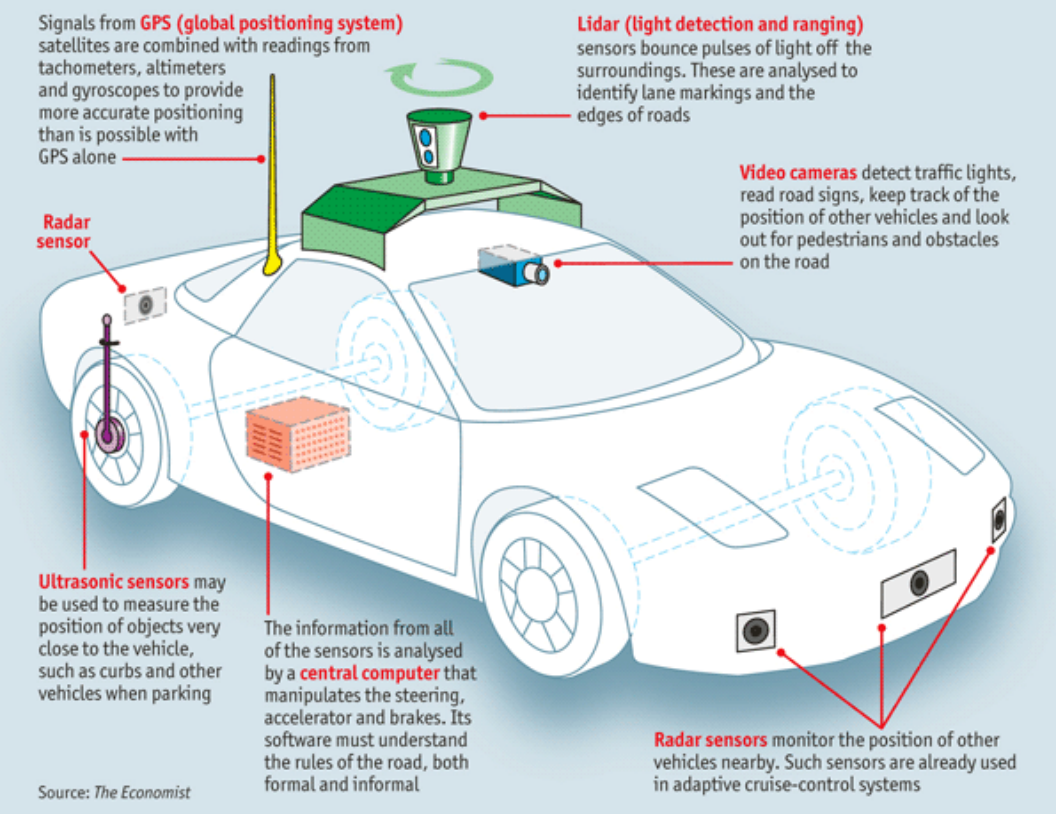

Figure 4: Sensors in a self-driving car (Source: The Economist)

It is not enough for an AV to "see" moving or new objects. It must also estimate their likely behaviours and integrate that assessment into a response decision. This requires machine intelligence: advanced algorithms that learn from experience.

Communication is another core activity for an AV. Digital communication with other vehicles (V2V) and, potentially, traffic infrastructure (V2I) can improve an AV's decisions. For example, researchers have designed and simulated infrastructure-based models for AV efficiency in traffic intersections. These include algorithms for managing fully automated vehicles, evasion planning protocols, and for managing semi-automated vehicles (Ticoll, 2015). All these depend on sending, receiving, processing and acting on digital communications with transportation infrastructure and, potentially, other vehicles.

In summary, an AV decision toolkit will include the following capabilities (Ticoll, 2015):

- Consult ultra-precise digitization of the existing physical world
- Identify and comprehend moving and transitory objects

- Interpret physical detection and digital communications from other vehicles and traffic management infrastructure
- Predict likely actions of moving and potentially moving objects
- Apply traffic and safety rules and protocols
- Apply the route plan
- Organize all these inputs logically
- Assess alternatives and apply decision rules to choose the vehicle's actions
- Make decisions regarding communication mechanisms and content with other vehicles, traffic management infrastructure, passengers, pedestrians, etc.
- Identify relevant data (including liability-related) for upload to local and cloud storage
- Learn from experience and change decision rules accordingly

Table 1: Predicted market introduction of automated driving systems. (Chan, 2017)

Organization	Confirmed and predicted product introduction	Predictions of readiness for autonomous vehicles
Audi/VW	2016 – Piloted Driving	Full AV by 2021
BMW	2014 – traffic jam assist 2014 – automated parking	Available by 2021
Bosch	2017 – Integrated Highway Assist 2020 – Highway Pilot	Auto Pilot by 2025
Continental		Available by 2020
Daimler-Benz	2014 – Intelligent Drive	Available by 2020
Ford	2015 – fully assisted parking	To mass produce AV in 2021
GM	2017 – Super cruise	
Google	2015 – Driverless Pod prototype	Available by 2018
Honda		Available by 2020
Hyundai		Available by 2030
Mobile Eye	2016 – technology ready for OEMs	
Nissan	2016 – traffic jam pilot 2018 – multiple lane control	Available by 2020
Tesla	2015 – Lane Assist + ACC 2016 – highly autonomous	Self-driving 2020–2025
Toyota	Mid 2010s – highly autonomous	
Volvo	2015 – traffic jam assist 2017 – Drive Me FOT in Sweden	Zero fatality cars by 2020

Projections such as the optimistic ones included in Table 1 sometimes fail to clarify or choose not to be specific about the type of automation features or operation modes in systems to be offered. However, it is apparent that the level of automation and exact capabilities of the products can differ considerably from one to another.

It can be said from the more recent forecasts that those previous predictions were too aggressive/optimistic in terms of market introduction, while the ones mentioned above in Table 1 and ? expect that 'real' autonomous driving (Level 4 and Level 5) are still around 10 years in future, see figure 5 to see the Gartner Hype Cycle 2019 (Alkim, 2019).

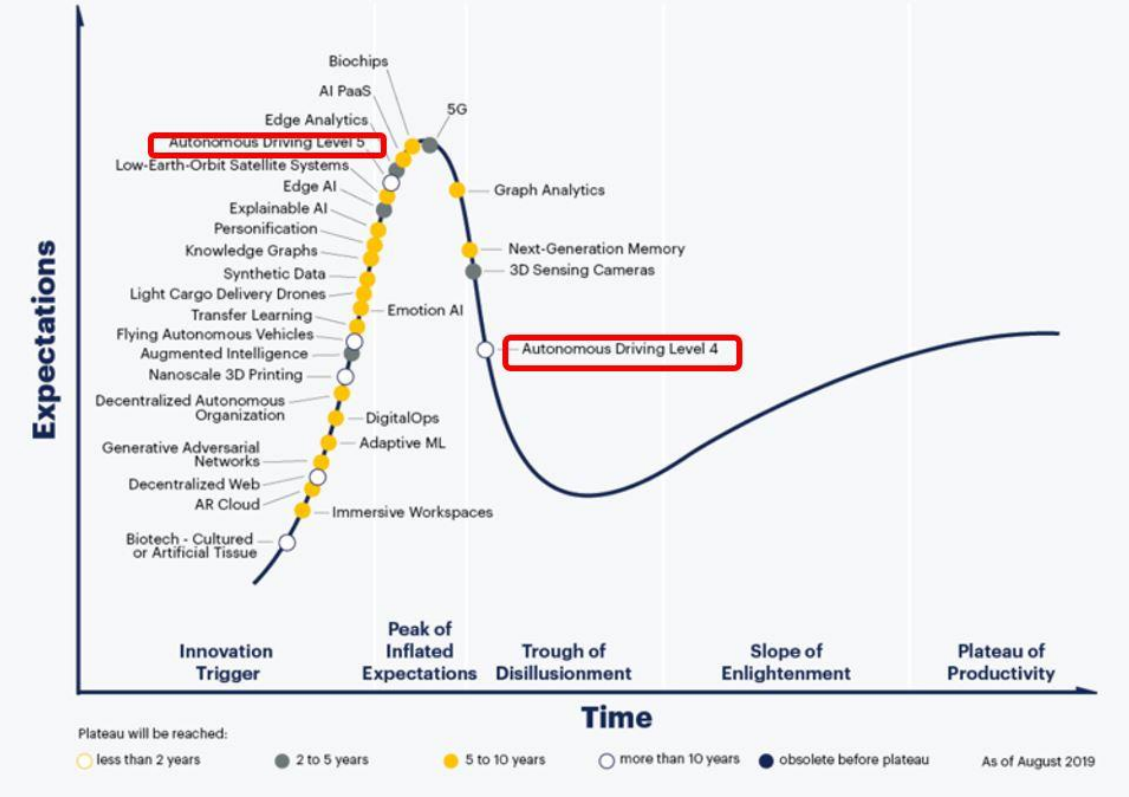

Figure 5: Gartner hype cycle for 2019 showing autonomous driving Level 4 and Level 5 (Alkim, 2019)

1.3. SAE Levels of Automation

Over the coming years, most new vehicles will gain increasing levels of automated driving capability (Ticoll, 2015). This report uses a 6-level model of vehicle automation from SAE International (SAE International, 2018) depicted in Table 2.

Level 0 comprises on no automation and driver is responsible over all the Dynamic Driving Task (DDT) even in the presence of active safety systems.

Levels 1 and 2 automation technologies perform specific driving tasks and provide warnings in some situations, but the driver retains overall responsibility for monitoring the driving environment. In Levels 3, 4, and 5, automation crosses a critical threshold. Now the technology system takes responsibility for monitoring the driving environment.

Nearly every car today has at least one automated feature: cruise control. In the SAE taxonomy, this is at **Level 1**, Driver Assistance, i.e., the automation of either steering or

acceleration/deceleration, but not both. Sophisticated Level 1 ADAS include adaptive cruise control, pre-collision braking, and lane departure warning.

At **Level 2**, Partial Automation, the vehicle system takes control of both steering and acceleration/deceleration. In October 2015 Tesla Motors was the first car company to roll out a suite of Level 2 capabilities. The company issued a software update for its Model S cars that are equipped with forward radar, a forward-looking camera, ultrasonic sensors, and digital braking control. The new capabilities can steer within a lane, change lanes, provide "active, traffic-aware cruise control" and collision avoidance, and prevent the car from wandering off the road. The technology can also detect a parking spot and parallel park the car. According to the company, the combined hardware and software use "real-time data feedback from the Tesla fleet, ensuring that the system is continually learning and improving upon itself." (Tesla Motors, 2015)

At **Level 3**, Conditional Automation, the vehicle system takes full-time control in specific operational design domain only, such as highway driving, dedicated AV lanes, or unobstructed city streets. In these modes, the driver must be able to take control when the system asks him/her to do so. A risk associated with Level 3 automation is that it has only seen limited research in scenarios where drivers, after relinquishing control, can respond in time when asked to take back control. At Level 3 the vehicles will also prompt the passenger to take over the tasks of the driver. If there is no response from the passenger indicating takeover, the system initiates dynamic driving task (DDT) fallback moving to a minimal risk condition.

At **Level 4**, High Automation, the vehicle's system takes full control in specific operational design domain, as in Level 3. The difference is that no driver participation is required in those modes or operational design domain or routes. For example, on dedicated freight routes, busways, or AV car lanes, Level 4 vehicles might run entirely on their own. Once vehicles depart such operational design domain, and in case of a conflict which the vehicle's system can't solve, the vehicles will then move to a minimum risk condition and might stop at a designated safe spot.

Table 2: SAE levels of automation (SAE International, 2018)

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	OEDR		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**			*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.				
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

With **Level 5**, Full Automation, the vehicle fully controls all driving modes irrespective of geography, road type, traffic conditions, weather, interactions or events in any kind of ODD (Operational Design Domain). Level 5 vehicles can drive anywhere, though they may need to go slow while learning a new (perhaps off-road) route. Steering wheels, floor pedals, and drivers are redundant in Level 5 vehicles as all occupants are passengers.

Based on SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, an updated version was released in June 2018. The SAE's driving automation levels are descriptive and informative, rather than normative, and technical rather than legal. Elements indicate minimum rather than maximum capabilities

for each level. In Table 2, system refers to the driving automation system or automated driving system (ADS), as appropriate (SAE International, 2018).

The automated vehicle (AV) industry is characterized by a large array of often overlapping technical jargon. Terms describe individual technologies as well as different levels of automation. This report distils these terms to focus on three market-related definitions as described in a report by Society of Actuaries (Mudge, et al., 2018)

- **Safe:** The driver is solely responsible for the driving task, but technology in the vehicle can improve safety by alerting the driver to risks or simply overriding driver action so as to avoid lane departures and/or crashes. These technologies are widely available in a range of levels from minimal crash mitigation to effective crash avoidance. They are being offered in an increasing share of new vehicles. The retrofit market for used cars does not yet exist.
- **Self:** These cars can assume responsibility for select driving tasks under specific road or weather conditions. They require an alert driver who is ready to take control under conditions the technology cannot handle. Self-driving technologies are currently emerging. Because their performance depends on driver intervention, their safety benefits beyond Safe technologies are not yet well understood, but their safety impacts are not expected to be substantially better than the best Safe systems. The industry will need to work hard to avoid them being worse.
- **Driverless:** These vehicles are responsible for all driving tasks. No driver is required during the trip. In the near term, their operation will be limited to defined locations during favorable weather conditions. These vehicles are still under development, although the technology has been implemented for certain low-speed vehicles. Waymo's deployment in Phoenix, Arizona, in early 2018 was the first public test of unattended driverless vehicles for on demand shared rides within a designated street network. Waymo began limited commercial on-demand service in December 2018.

Safe and Driverless are most relevant for the insurance industry since they 1) are likely to have the largest overall impact on vehicle safety and 2) they frame the range of changes that will affect the insurance industry.

2. Methodology

2.1. Data collection

The work within this Task 2 of Activity 4.2 is divided into three phases where this report constitutes the third phase. The phases are:

- Phase one: Methodology and templates, initial desktop analysis
- Phase two: Project inventory and selection of projects for a structured analysis on impacts.
- Phase three: Reporting from ongoing projects, selection of projects on level 4 highway pilot for analysis including elaboration on impacts in monetary terms. Workshop on impacts and final report.

The argumentation for this three-stage process is that in the first phase we can agree on methodology for data collection (Data is in the first two phases described as information and text and it is only in the third phase where data in the form of statistics will be used) and, based on literature, decide on which effects we will focus on in the second phase. This is reported in the first draft of the deliverable. In the second phase, we collected information from ongoing and recently finalized projects. The aim was to take a relatively broad view on automation in terms of levels of automation and services to study. The reporting is primarily descriptive and focus on lessons learned and conclusions on impacts relevant for road operators. For the final version more results were collected from ongoing projects as well as the execution of a workshop with representatives from Road operators and OEMs. The workshop was carried out in October 2019 and results from that workshop are included in this report.

This activity relies on the input from other studies, tests and trials. Horizon2020 projects are one important input but there are also other sources, such as national projects or projects outside the EU.

There are other ongoing initiatives for collecting and describing projects and we are collaborating or following their work to be more efficient. Other initiatives that were identified are Connected Automated Driving Roadmap (ERTRAC, 2019), the Dutch KnowledgeAgenda (Ministry of Infrastructure and Water Management, Department of Transport and the RDW-Vehicle-approval, Netherlands, n.d.), MANTRA (Penttinen, et al., 2019) and CARTRE (Connected automated driving.eu, n.d.). In addition, the newsletters OmAD (RISE Viktoria, n.d.) and Smart Mobility - News and Comments (Drive Sweden, n.d.) were also scanned for relevant projects.

Since information of the relevant projects is collected through various sources and by different persons, a structured approach was used. For the collection of information in the

two first stages an Excel-file was used as a template, see description in Appendix 1. The Excel file was shared online to accommodate input from all partners.

2.2. Workshop on impacts and costs of Highly Automated Driving: Torino 2019

A multi-stakeholder workshop took place in Torino, Italy on 1-2 October 2019. The workshop put the focus on ODD, costs and benefits of highly automated driving. On Day 1 the workshop discussed the Operational Design Domains, their evolution path and the role they can play in type approval and certification (proceedings from day 1 can be found here). On Day 2 the workshop examined and discussed the costs and benefits of highly automated driving based upon existing research and projects (proceedings from day 2 can be found in Appendix 9.2).

The workshop welcomed everyone involved in shaping innovation in the automated driving. Overall, the Workshop attracted in all 37 participants with 15 from industry and the private sector, 17 from public sector and road operators across EU, and 5 representing academia and research.

An excel based MCDA (Multi-criteria decision analysis) was used during the workshop as a tool for discussion and collecting data. The workshop gave us an excellent discussion around identified impacts, benefits & costs and also some additional impacts, costs and benefits related to highly automated driving in general but also for chosen use cases and scenarios. The findings on impacts and benefits are described in Chapter 3.

2.3. Clustering of results

The information collected through the desktop analysis in phase one was structured into topics based on what came up in the desktop analysis and then iterated within the Sub-activity 4.2 group for further refinement. The process ended up with the following topics to be studied further in this sub-activity:

- Mobility and usability
- Safety
- Capacity, traffic flow and congestion
- Operations of road authorities, robustness and reliability
    - Maintenance, incl. road works as well as cleaning and snow clearance
    - Traffic management
- Parking
- Public transport

- Environment and health
- Physical infrastructure
- Digital infrastructure
- Planning
    - Planning
    - Public space and land use
- Costs
- Reliability and simplicity
- Active travel

For most of these, information was found through the desktop analysis and was a starting point for phase two while some was more difficult to find information on. Most of the information was used as a base in the excel tool for the Torino stakeholder workshop.

The initial findings from the desktop studies are presented in Chapter 3 in this report. In phase one, the overview was presented descriptively. In phase two information on benefits were presented together with impacts of automation on road operators and in phase three information on costs was added along with findings from the stakeholder workshop. Information in Chapter 3 and Chapter 4 is hence structured under the following headlines:

- Identified impacts (Chapter 3)
    - Summary of impacts of highly automated driving from a road operators' perspective
- Identified benefits (Chapter 3.12)
- Identified costs (Chapter 4)
- Potential adaptation needed
    - This deals with: What need to be changed from today's system? New expertise required, quality of services need to be changed, adapted maintenance of roads and pavements, etc.
- Reliability of results / Information gaps
    - Since this is a new and rapidly growing research area where lots of information is added on a more or less daily basis it is important to distinguish between speculations and facts. In this chapter the origin of the information is described and valued, and an effort is made to conclude whether there is clarity and agreement in the findings or if more information is needed on the topic.

3. Impacts of automation

In this section impacts of automated driving, based on literature and the project inventory, are summarized. The clustering of the impacts is based on the findings from the literature study in phase 1 but also taking goals and areas of responsibility for road operators into account.

Smith (Smith, 2016), suggests dividing AV impacts into direct and indirect groups. While direct impacts are the ones which have a relatively clear cause-effect relationship with the primary activity or action - in Figure 6, they are in the upper left, and include safety, vehicle operations energy/emissions and personal mobility - indirect impacts summarizes the broader effects of the individual direct impacts and are produced as the result of a path/chain of impacts, often with complex interactions and external factors.

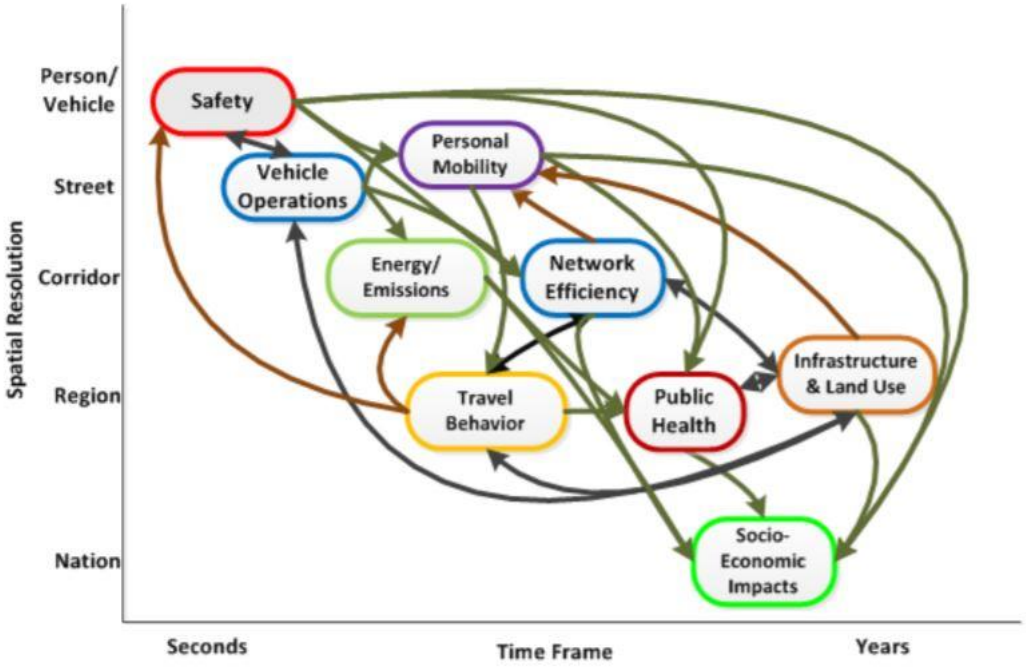

Figure 6: Impact areas (Smith, 2016)

In Figure 6, forward links that are represented in green arrows, these impacts are those in which short term changes in an impact area affect longer term changes in another impact area. For example, a change in personal mobility, such as an increase or decrease in shorter walking trips will overtime affect the longer-term impacts of public health. Feedback links are represented in brown, these impacts are those in which more holistic or wider

reaching changes in impacts affect shorter term and more localized changes in other impact areas. For example, a change in land use and zoning policy will affect the options available for travellers to make personal mobility choices. Finally, those links going in both directions are in black and denote a mutual impact relationship.

Since this report focuses on impacts for road operators not all direct and indirect impacts mentioned by Smith (Smith, 2016) were included. While the approach to identify impacts for road operators differed compared to some literature mentioned in the report, it was interesting to see that most identified impacts could be found in most of the studies around impacts of AV.

It is important to understand the magnitude of uncertainties while evaluating these impacts, these uncertainties are a result of both the technology in itself as well as how these technologies are adopted. (Wadud, et al., 2016) suggests the share of ownership vs. mobility services in an automated future is possibly the largest uncertainty in impact modelling, as these affect most of the impacts mentioned in the sub headings below.

3.1. Impacts on mobility

There are many perspectives that state that automated vehicles will have a significant impact on people's mobility and travels. However, there are different opinions how this will happen. There are perspectives that indicate that automated vehicles will increase the car sharing and that vehicles will be used more effectively. There are also different standpoints how car sharing will affect the total vehicle fleet, and the reduction in the size of the vehicle fleet differ among these standpoints. However, widespread car sharing requires technology that enables automated vehicles to drive without a driver (Chan, 2017).

At the same time, there are many perspectives that indicate that car sharing, and joint ownership will not be attractive enough to have an impact on car ownership and travel patterns. Instead, the total travel will increase since automated vehicles will make it even more attractive to travel by car (Barcham, June 2014). Studies also indicate that comprehensive changes regarding legal structures and social norms need to be determined in order to achieve a high proportion of car sharing (Barcham, June 2014). Shared ownership of cars does not lead to less trips in itself, for that the rides need to be shared.

A report on impacts of AV by MANTRA (Penttinen, et al., 2019) highlights KPIs such as value of time travel, number of trips, distance travelled, share of car & public transport, travelling time and comfort, accessibility etc. as the ones which affects users the most but

also in turn affects road operators as well. To summarize the findings from MANTRA (MANTRA, 2019);

- Value of travel time saved in automated vehicles is substantially lower compared to that for the current car drivers
- Automation would almost certainly increase the number of car trips if "ride-shared" on-demand mobility services are not realized on a mass scale in future
- We will see an increase in kilometers travelled due to greater availability of AV and the amount of accessibility it provides
- Increase in travel comfort is certain while the reliability of AVs can dip down before eventually with optimization it will go up.

Automated vehicles can also facilitate independent mobility for elderly, children, handicapped or others who are not allowed to drive themselves. How the legal and practical framework for this will look is yet to be decided but the potential benefit for these groups is of course significant. However, at present even the best examples of highly automated vehicles require a presence of a driver/conductor or any human to take control in case of need or in complex situation (Level 4). This won't change until we have Level 5 vehicles on the road in majority which might lead to a conclusion of mobility not being affected as much in the beginning and taking off once the adoption of these vehicles is significant. Another reason for the slow adaptation to automated vehicles may be the low confidence in new technologies for not only consumers but also suppliers and policy makers.

3.2. Impacts on traffic safety

Highly automated vehicles will be equipped with an array of sensors and crash avoidance systems. Those technologies will also be available to provide driver support and crash avoidance in manual driving and in driving at lower levels of automation (1 and 2). Therefore, it can be expected that these vehicles will be safer in general operation (Geissler , et al., 2016).

Further, (Hayden, et al., 2018) estimate highly automated driving to reduce road crashes by 50% and fully automated driving by 90%. However, the overall safety impact of these vehicles would naturally depend on their penetration into the vehicle fleet and their relative usage (Kulmala & Carsten, 2015). An AV which is supposed to have advanced driver support systems and more, handled by the vehicle itself (differs on automation level of the vehicle) will only prove to be safer than conventional vehicles. Hence the impacts on road safety are expected to increase with higher levels of automation (Kulmala, et al., 2019).

Additionally, faster reaction time can be achieved with the usage of automated vehicles, and driver mistakes can be largely eliminated making AVs safer.

An automated and connected vehicle may also reduce the risk of accidents via the coordination between the infrastructure and/or other vehicles also referred to as V2X connectivity: Vehicle to X, X being another vehicle (V2V), the infrastructure (V2I) or another element). The fact that vehicles can communicate enables adjustable routes for example, the routes can be adjusted so that hazardous situations can be avoided. V2X connectivity will also affect the headway for automated vehicles with and without connectivity. Long term (well beyond 2035), when the penetration rate is very high and systems are very reliable, the time headways may be significantly smaller, with good V2X connectivity to deliver cooperative ACC and smart platooning (Rämä, et al., 2018). This will help to eliminate shockwaves and secondary crashes and could help to eliminate crashes in poor visibility conditions such as fog, where currently there are still significant multi-vehicle collisions often resulting in serious injuries and fatalities (Kulmala & Carsten, 2015).

However, there are different points of views regarding if the communication between vehicles , and advanced sensing capabilities in general, will generate an improved traffic safety. An overconfidence in automated vehicles' capabilities may cause the opposite effect. Vulnerable road users (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 automated vehicles 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) (Rämä, et al., 2018). The drivers, pedestrians and cyclists may take riskier decisions in traffic related situations, which consequently may impair the road safety. (Land Transport Authority, Singapore, n.d.)

A number of numerical estimates of safety impacts have been produced via modelling and simulation. Some studies assess that urban robot taxis or "chauffeur" type of automated cars will be able to avoid about 70% of crashes involving cars and that the relative accident rate of highly automated driving will be around 15-20% of that in manual driving (Kulmala, et al., 2019).

Eventually, the safety impacts are the product of the changes in exposure, crash risk and crash consequences. It is expected that both crash risk and consequences will be reduced considerably, especially after the transition period. Exposure, unless most automated vehicles will be in (ride) shared use, can drastically increase, compensating to a meaningful extent the safety gains from reduced crash risk and consequence (Kulmala, et al., 2019).

Results from (CARTRE, 2018) also estimated that there will be a great decrease in number of injuries and fatalities, due to automation. The results also highlighted the role of road authorities in maximizing the benefits of automated driving in road transport.

(Litman, 2018) believes that AVs could reduce crash rates by 90% due to elimination of human error, but also says that there will be additional risks the technology could introduce, such as:

- Hardware and software failures,
- hacking,
- Increased risk taking (offsetting behavior/risk compensation),
- Platooning risks,
- Increased total vehicle travel,
- Additional risks to non-car travellers,
- Reduced investment in conventional safety strategies.

Consequently, it is not an easy sail for AVs to reach the optimistic and simulated safety scores. There are significant challenges in the interaction with drivers of nonautomated vehicles and with vulnerable road users (pedestrians, cyclists and riders of two-wheeled motor vehicles) (Geissler , et al., 2016). There is also a significant challenge in delivering systems with very low failure rates (Kulmala & Carsten, 2015), and in addressing the design challenges in achieving safe cooperation between human operators and automated systems (Geissler , et al., 2016). The later shall see improvements as the technology improves as well as with adoption of these technologies.

Another challenge for AVs could be more of a design challenge cause due to human - machine interface (HMI) (Kulmala, et al., 2019). HMI can be seen as a touchpoint to AVs as they are the things which a user will experience and interact with when in a AV. Hence, HMI needs to be well-designed, provide appropriate levels of information when needed, and suppress superfluous information. Operator monitoring by the vehicle is likely to be required, to ascertain driver availability in take-over situations (fall back conditions). Mode errors, in which drivers misinterpret the level of automation or misunderstand the functionality or capabilities of the currently engaged system(s) are likely to occur. Confusion may arise when drivers switch vehicles and encounter capabilities and HMIs with which they are unfamiliar. These problems are likely to be aggravated by the insistences of vehicle manufacturers on having brand-specific design themes. This might not have a big impact with shared AV and full autonomous robo - taxis since the user wouldn't need to interact much with vehicles in those cases but also possibilities of smart fleet management systems adopted by vehicle manufacturers can mitigate the issue by having an operator present remotely in case of need.

Tackling challenging and extreme weather conditions will also be a challenge for AVs. Sensor limitations may preclude automatic operation in challenging conditions such as snow ((Kulmala & Carsten, 2015), (Geissler , et al., 2016)). Sensors may also be distracted and provide false detections as well as related alarms, increasing crash risks and hence, traffic safety.

3.3. Impacts on capacity and traffic flow

There are currently different points of view how automated vehicles will affect the road capacity and traffic flow. At an early stage of the implementation phase, automated vehicles are estimated to increase the congestion. One of the reasons is that automated vehicles will with most certainty drive more carefully and obey regulations in terms of speed limit and safe following distance which may not be the case with a human driver. This is a complex relation however, since less accidents and more harmonised speeds may also have a positive impact on traffic flow. The increase of the congestion is expected to eventuate in both motorways and urban areas. However, the urban areas will probably experience a greater amount of congestion. A study conducted in the UK indicates that the congestion problems will not improve until automated vehicles stand for at least 50-75% of the car fleet (Atkins, 2016), and this will happen 2050-2060 at the earliest. (Litman, 2018) In order to reduce the initial negative impacts regarding traffic flow, different measures can be implemented at the introduction phase of automated vehicles. One of these measures are implementing zones where automated vehicles can be introduced and tested. The cities can thereafter gradually expand these zones as the automated vehicles increase in numbers (ITS International, 2016).

The capacity problems due to cautions automated vehicles with long headways would be eliminated with lower headways, which could be maintained to efficient sensing and connectivity. MANTRA simulations indicate that at 1.0 second headways vehicles with highway autopilot would improve the capacity on motorways (Van Der Tuin et al, 2020).

The traffic flow can also be affected by the fact that automated vehicles frees up time for the driver to do other things than driving. This may affect the perception of the car as a means of conveyance, the car may be perceived as the optimal means of transportation at the expense of other modes. This may impact the traffic flow and the congestion in negative terms. Another aspect that may have a negative effect is, that the automated vehicles may be enforced to drive back without a passenger, which cause unnecessary driving and increases the number of vehicles on the roads. The change in the perception of the vehicle as mean of conveyance may also increase the risk of urban sprawl since people may be willing to travel a longer distance in comparison to before (Litman, 2018).

However, there are no unanimity regarding which form of ownership that will dominate, if private ownership or joint ownership will dominate. If joint ownership were to be the dominate form of ownership, a positive effect on the traffic flow and congestion may occur since the total car fleet would decrease and less household will own their own vehicle. (Litman, 2018)

Connectivity enables a decrease in headways, resulting in an increase in capacity on highways. (Penttinen, et al., 2019) pointed out a study about the impact of connected vehicles for different market penetration rates using microsimulation. It concluded that an

increasing market penetration of Cooperative Adaptive Cruise Control (CACC) will lead to an increased road capacity up to 3970 vehicles/hour/lane for a 100% CACC scenario. Combined with Adaptive Cruise Control (ACC) vehicles, these only results in slight additional increases in capacity as can be seen in Table 3.

It was also concluded through various studies that ACC equipped vehicles generally cause additional congestion, whereas CACC reduces the congestion. Likewise, ACC results in less stable traffic, CACC in more stable traffic (Penttinen, et al., 2019).

Table 3: Prediction of highway lane capacity (vehicles/hour) of ACC and CACC equipped vehicles (MANTRA, 2019)

		Percentage of CACC Vehicles								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
Percentage of ACC	10%	2065	2090	2170	2265	2389	2458	2662	2963	3389
	20%	2065	2110	2179	2265	2378	2456	2671	2977	0
	30%	2077	2127	2179	2269	2384	2487	2710	0	0
	40%	2088	2128	2192	2273	2314	2522	0	0	0
	50%	2095	2133	2188	2230	2365	0	0	0	0
	60%	2101	2138	2136	2231	0	0	0	0	0
	70%	2110	2084	2155	0	0	0	0	0	0
	80%	2087	2101	0	0	0	0	0	0	0
	90%	2068	0	0	0	0	0	0	0	0

Another parameter that may affect the traffic flow is how drivers of conventional vehicles and pedestrian will rely on the automated vehicles' capacity and capabilities. An overconfidence in the vehicles' capacity and capabilities could lead to dangerous situations, which can affect the traffic flow (ITS International, 2016).

Road capacity may also be improved by the possibility of narrower lanes which could make room for an extra lane on the road, platooning and less stops in the traffic. However, that can only be achieved when there are only automated vehicles on road. However, having dedicated lanes for automated vehicles may also reduce the capacity of the road for conventional cars as the cost of providing higher safety (EU EIP Activity 4.2, 2019).

Narrower lanes and platooning could lead to more wear on the road surface since there is less random variation in lane position of the vehicles. If connected and automated vehicles could utilize narrower lanes, this has potential to increase capacity, but only if all the vehicles are connected and automated (MANTRA, 2019). In this hypothetical 100% penetration rate scenario mentioned above in Table 3, the current 3+3 lane roads could be deployed to 4+4 lane roads, increasing the capacity accordingly. However, this is currently just a theoretical estimation, and would require all the vehicles on the road to be connected and automated (Penttinen, et al., 2019).

(Atkins, 2016) in their research on impacts of CAVs on traffic flow in UK, mention that connected and automated vehicles could impact network performance, traffic flow and capacity as:

- The potential for reductions in network performance, rather than improvements.
- Substantial benefits may not be achieved until high levels of connectivity and automation.
- Benefits to congested networks.
- Low speed urban areas may benefit most from low-tech driver assistance capability.
- Reliability is likely to improve.
- Benefits are not constrained to one class of user.

3.4. Impacts on parking

It is difficult to predict whether automated vehicles will lead to an increased or decreased demand for parking. This will depend on parameters such as future travel patterns, which form of ownership will dominate and if the vehicle will require a driver when parking or driving.

When it comes to travel, there are studies that indicate that automated vehicles will make cars more attractive as a mean of transportation. This suggest that the demand for carparking will increase. However, if joint ownership would dominate it may reduce the overall demand for parking since the vehicle can pick up additional people instead of being parked. The decreased demand for parking as a result of automated vehicles will however not be relevant until level 4-5 on the scale of automation, presupposed that car sharing is the most common way of traveling. It may also happen that automated vehicles in combination with a high level of utilization generate empty vehicles on the road, which will result in negative effects.

The fact that automated vehicles can drive and park without a driver can also influence where the parking will be located. AV will make it possible to locate the parking on less central places in comparison to today and can also reduce parking facility costs by allowing vehicles to park further from destinations. But most users will probably want their vehicles available within five or ten minutes, and so must park within a mile or two, that however can only occur if the cars are Level 5 automated. If the cars can drive fully automated in dedicated areas like car parks, that could lead to less area demand for parking while the parking space for each car can be narrower since the doors don't need to be opened in such scenarios.

3.5. Impacts on public transport

As for today there are different perspectives regarding how automated vehicles will affect the public transport. A direct effect is that public transport can make a use of automated vehicles. Some stakeholders indicated that public transport will become less attractive since privately owned automated vehicles can provide a more comfortable way of traveling (EU EIP Activity 4.2, 2019). The conventional public transport will thereby be considered primarily as mean of transportation for those who can't afford to travel with automated vehicles, rather than the primary means of travel for a large proportion of the population. However, other studies indicate that automated vehicles only can be considered as a complement to the conventional public transport since public transport can handle a high number of travellers more effectively. (Litman, 2018)

It's of importance to emphasize that there are probably major differences between rural and urban areas, as well as between different commute areas. In many cities, public transport is the most effective way of moving a great amount of people between their work and home. If automated vehicle where to replace a large proportion of the commute travels, significant infrastructure investment is required. Since spaces in urban areas can be very restricted, the demand for public transport may not be outrivalled by the automated vehicles. In the rural areas, where there are less passengers, automated vehicles can fill an important function. The vehicles could increase the accessibility where public transport, as for today, could not deliver good enough accessibility in an efficient way.

An article from UITP clearly shows that automated vehicles should not be perceived as a substitute for the capacity-strong public transport, primarily for space reasons. However, automated vehicles can serve as a great complement to the traditional public transport. For example, area-specific call-controlled minibuses can act as a complement to the local public transport. (International Association of Public Transport, UITP, 2017)

Another study suggest that automated vehicles primary have a competitive advantage when it comes to medium-distance journeys, and that is in comparison to public transport based on railway. The travel time can be significantly reduced since the journeys between home and the station could be avoided but you can still use the time to other things than driving, as you would on a for instance a train. For longer journeys, which is compatible with high speed trains, cars will not be able to compete in the same way. (Augustsson, 2016)

3.6. Impacts on the environment

The expected environmental effects that automated vehicles generate vary depending on the assumptions. Which assumptions will prove to be correct, such as how the total vehicle

fleet will look like, which form of ownership that will dominate and so on will have a big effect on the environmental outcome.

There are different perspectives that indicate that automated vehicles would have a negative impact on the environment. This is often supported by the fact that the usage of cars will increase, which will affect the environment in negative terms. Why the usage of cars may increase when implementing automated vehicles could have different explanations. For example; new demographic groups that will be able to drive, such as elderly, handicapped and the children, and the perception that an automated vehicle is the optimal means of transportation etc. Another viewpoint is that the automated vehicles would weigh more and drive faster than a regular car, and thereby increase the emissions. (Giarratana, 2016) But of course, there is a relation with the parallel development towards more electric-powered vehicles.

Self-driving technologies require additional equipment, and vehicle manufactures are likely to market seats that turn into beds and mobile offices, which can increase energy consumption and emissions (Litman, 2018) but negative effects which derive from human errors can also be eliminated with these technologies (Ensia, 2015). If the prediction that, the congestion will reduce, prove to be correct, this may have a positive effect on the environmental aspects (Giarratana, 2016). By increasing total vehicle travel and vehicle size (if cars become moving offices and bedrooms, as some experts predict) they may increase total pollution emissions. Hence, autonomous operation can also increase congestion, energy consumption, pollution and roadway costs.

There are also perspectives that indicate that automated vehicles will generate in positive effects regarding the environment. Automated vehicles may create a smoother traffic pattern. This includes, among other things, minimizing accelerations, traffic stops, and unnecessary driving associated with navigation and parking (Ensia, 2015). However, the positive environmental effects are not expected to occur until level 4-5 on the scale of automation. There are also studies that indicate that positive effects regarding the environment are marginal and that electrical vehicles will be the primary source to the potential reduction of emissions (ITS International, 2016).

Impact to the environment especially emissions might be improved with automated, more fuel efficient and effective vehicles/transportation services but will worsened due to more traffic and reduced capacity on a macro level. Another reasoning at the workshop was more demand will lead to more vehicles on the road which in turn will have more negative impact on emissions. (EU EIP Activity 4.2, 2019)

3.7. Impacts on physical infrastructure

When implementing automated vehicles, the infrastructure will be of great significance. One of the key aspects is the marking of the lanes on the road, and that with the preconditions of the automated vehicles' system as they look today and in the nearest future. It´s mainly about how the road markings will look (the harmonization) as well as how the pavements and edges will look. A part of the challenge is how the infrastructure will work under varied visibility conditions as well as how it will be implemented in a more complex urban environment.

Due to the significance of the lane markings, additional maintenance is required. The lane markings must be distinct and visible if the automated vehicle will be able to drive and navigate in a proper way. Similar predictions might be made for other road furniture especially road signs and guide posts, while an automated vehicle might get all such information over the air or through digital maps with embedded ODDs eventually, it would still be essential for conventional vehicles to have such road signs present for their information. If an early adoption of automated vehicle is the ambition this needs to be prioritized. (Public Sector consultants and Center for Automotive Research, 2017)

The European Commission (EC, 2017) states in the C-ITS Platform's II Phase final report that research and standardization work on infrastructure changes related to automated driving should cover the following non-exhaustive list:

- Decent quality and visibility (contrast) of lane markings, in particular on motorways, dual carriageways and key cross-border routes (TEN-T) to facilitate lateral control for automated driving.
- Clear visibility of road infrastructure for vehicle sensors and the driver – including road signs, speed limit signs, traffic signs indicating change of speed limits via marking entrance to towns and municipalities (maintenance to avoid covered through bushes, or temporarily by snow, and are not clearly recognisable for vehicle systems at the required distance).
- To present static and dynamic traffic rules (or signs) also in digital representation in data bases, in maps and directly on the road. When using both physical road signs and the digital infrastructure, mismatches may occur, especially for dynamic signs. Also, sometimes the regulation becomes effective when physical signs have been installed, and sometimes when the regulatory documents are published. Similarly, the digital representation is sometimes based on the regulatory documents, and sometimes by interpreting the physical signs. A higher quality of data and further harmonization of regulation will benefit CCAM.
- Availability of usable hard shoulders for safe, automated emergency stops.

- Light-signal systems with communication facilities can, in the long run, contribute to the reliability of digital road infrastructure.
- VMS often have scanned LED arrays which are incompatible with vehicle cameras. VMS therefore need standardised triggers (pulsating LEDs and/or short/long range communication).
- Ensuring availability of existing and intact fences where needed on motorways, dual carriageways and TEN-T to minimize risk regarding hazardous situations with large wildlife (such as deer, moose, etc.).
- Identification and communication about platooning levels for a specific road segment statically or dynamically assigned (e.g. number of vehicles allowed in a platoon)
- Allocation of dedicated lanes or areas where economically viable (e.g. automated shuttles are given access to existing bus lanes)

MANTRA (Ulrich, et al., 2020) mentions physical infrastructure attributes of automated driving, which can be seen in the Table 4 and it further concludes some ODD attributes for physical as well as digital infrastructure relevant for automated driving in general, can be seen in Table 5.

Infrastructure attribute	Sub-attributes	Comment
Road	Road type	Basic road types such as motorway, highway, street, private road indicate separation of carriageways, intersection arrangements, types of road users etc.
	Special road sections	Additional requirements for critical road sections such as tunnels, bridges, toll plazas etc.
	Separation of automated vehicles	Dedicated lanes or areas; permanent or temporary such as night time only
	Pavement of road	Ease of detection of the roadway
Speed range	Speed limit or recommendation	The speeds in which the automated driving system has been designed to function. Either static or dynamic speed limits/recommendations. Dynamic ones relate to traffic management
Shoulder or kerb	Wide shoulder	possibility to use as “safe harbour” if ODD ends
	Lay-bys or parking areas	as above
	Passenger pick-up/drop off areas	necessary for automated shuttles and robotaxis
Road markings	Existence of lane markings	lateral positioning
	Visibility, machine-readability	visibility to vehicle sensors
	Markings indicating use by automated vehicles	indicating of right to use or prohibition of use by highly automated vehicles
Traffic signs	Visibility, machine-readability	visibility to vehicle sensors
	Signs indicating use by automated vehicles	indicating of right to use or prohibition of use by highly automated vehicles
Road furniture	Landmarks	Static physical landmarks possible equipped by sensor reflectors or radio beacons or similar to support accurate positioning
	Gantries for road signs	indicating of right to use or prohibition of use by highly automated vehicles
	Gates and barries	Access to dedicated lanes, roads or areas
	Road lighting	Support to automated vehicle’s vision system
Infrastructure maintenance	Winter maintenance (snow removal, de-icing)	Visibility of road markings and traffic signs in adverse weather conditions
	Road maintenance incl. road marking painting, clearing of vegetation	Quality and visibility of road markings and traffic signs
	Inspections of infrastructure	Inspections according to standardised test/inspection protocols for both physical and digital infrastructure

Table 4: Physical infrastructure attributes of automated driving, MANTRA (Ulrich, et al., 2020)

Table 5: List of ODD attributes for automated driving by MANTRA (Ulrich, et al., 2020)

ODD attribute	Physical / Digital infrastructure	Static / Dynamic
Road	Physical	Static
Speed range	Physical	Static
Shoulder or kerb	Physical	Static
Road markings	Physical	Static
Traffic signs	Physical	Static
Road furniture	Physical	Static
Traffic	-	Dynamic
Time	-	Dynamic
Weather conditions	-	Dynamic
HD map	Digital	Static
Satellite positioning	Digital	Static
Communication	Digital	Static
Information system	Digital	Static

3.8. Impacts on digital infrastructure

Automated vehicles are supposed to be independent of road infrastructure elements, according to some, and to rely solely on the technology it holds (built-in sensors etc). However, the technology which is used in today's advanced driver assistance systems relies heavily on the quality of infrastructure elements like adequate reflectivity of lane markings or the readability of variable message signs (VMS) and is therefore limited in localization precision (Carreras, et al., 2018).

To implement highly automated driving, there are several different aspects which need to be considered concerning the digital infrastructure. First one being necessity that the vehicles are connected; between vehicles and infrastructure, as well as between vehicles and vehicles. To ensure this connectivity various digital infrastructure efforts are therefore required. This mean that, sensors, connectivity and cloud services are required.

In practice, a suggestion from Farah (Farah, 2016) is to equip the road surface with equipment needed to implement sensors on and around road markings in the future. The sensors' function is to estimate the traffic situation and the vehicles on the road. The

accuracy of these estimations will depend on the distribution of the sensors along the road network. The sensors will act as the link between the vehicles and the digital infrastructure. The sensors can thereby provide information to the vehicles, such as queue-warnings, information about the surrounding environment etc. Supposing a scenario where no sensors are implemented, ITS-messages needs to be shown through signs to the automated vehicles.

There also studies that indicate that it´s more cost efficient to implement sensors in comparison to the conventional ITS-services. Additionally, there is a need for cloud services in order to store data, develop intelligence and develop the ability to anticipate traffic scenarios (Farah, 2016).

Farah (Farah, 2016), also suggests a need for digital maps and a road database which will make it possible for the vehicles to navigate, plan and localize using the data provided over the air. The database will integrate the road with the infrastructure (both physical and digital) through a high precision map. The map will be dynamic as well as static.

Secondly, exact positioning of the vehicle is required. The main challenges when it comes to V2I-systems is the exact positioning of the vehicle, that the vehicle will receive the relevant information at the right time and that the information is presented in correct manner.

All automated vehicles at a certain SAE level 4 depend on precise localization, Global Navigation Satellite System (GNSS) reference points become a very important element of the physical infrastructure, especially in areas with missing or bad GNSS coverage such as, e.g., in tunnels. (Carreras, et al., 2018) suggests, in some such situations, the physical readable information about lane markings and speed limits can be replaced or supported by map content based on static information. This will provide the vehicle to still receive required information (now from a different set of sensors) to function in its normal form without initiating DDT fall back. Here it is the responsibility of road operator and map provider to provide such maps in critical areas.

(Carreras, et al., 2018) further highlighted that maps can be further enhanced by additional layers of dynamic content, such as information about temporary changes (e.g., roadwork information, speed limit regulations, and warnings about obstacles on the road). However, conventional VMS will remain important due to the long transition phase of estimated several decades between conventional road users and automated road users as the adoption of automated vehicles takes place and as the technologies in AVs keeps on improving.

In the time of improving V2X communications, the communication between vehicles and infrastructure can be implemented not only by short range communication standard ITS-G5 but also by cloud services based on cellular communication to what we also refer as hybrid communication (Carreras, et al., 2018). This enables AVs to see (get informed) beyond what is called electronic horizon with the help of state-of-the-art road infrastructure data as shown in Figure 7. By using such method (Carreras, et al., 2018) states that it could extend the range of the horizon in AVs to 700-800m or a time equivalent of 20 seconds. This gain can help in route planning at critical traffic points.

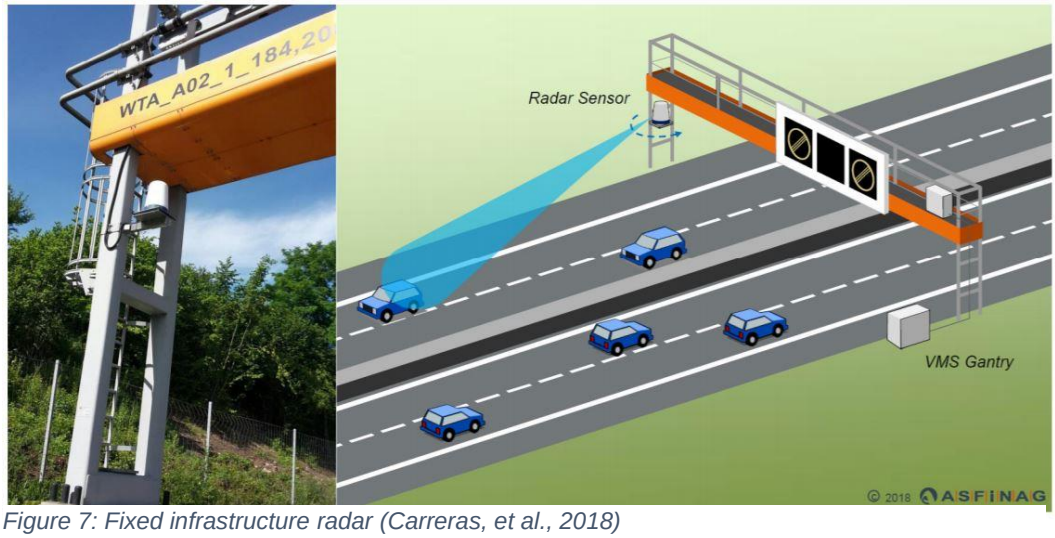

Figure 7: Fixed infrastructure radar (Carreras, et al., 2018)

Ideally in a mix traffic situation, the data fusion of vehicle sensor data, map information and additional road infrastructure data is required to meet optimal road safety aspects. Data of the digital infrastructure, see Figure 8, can be even used to guide the mixed traffic by suggesting an optimum distance (gap) between vehicles in order to, e.g., support lane merging or dissolve platoons (Carreras, et al., 2018). This active guidance of automated vehicles is required when aiming at an efficient traffic flow.

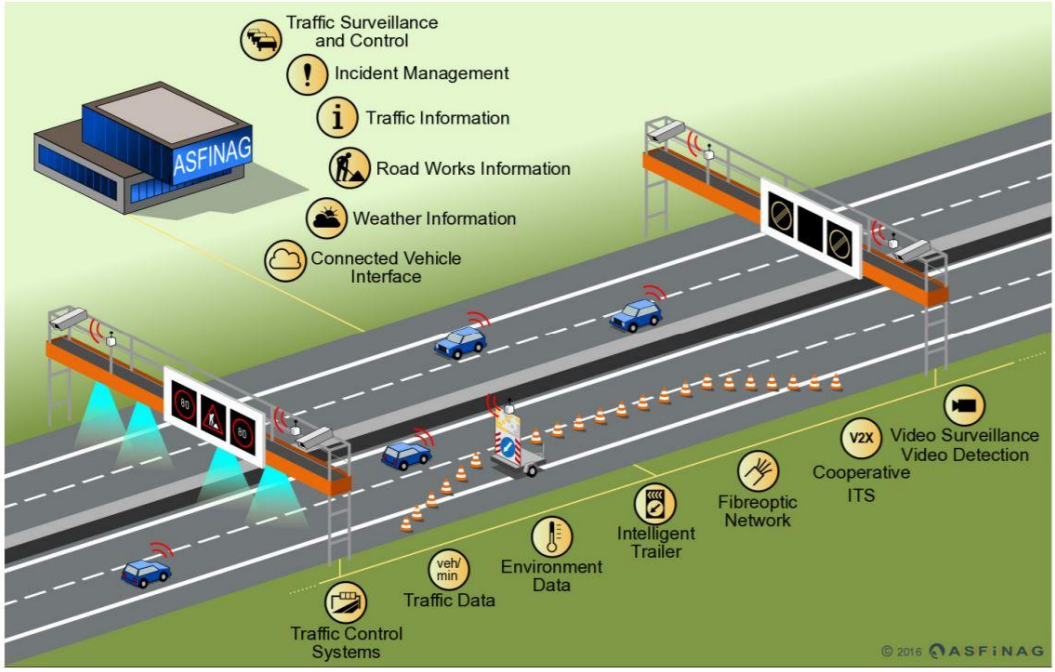

Figure 8: State-of-the-art elements of a digital infrastructure (Carreras, et al., 2018)

To structure the various means of support that infrastructure can provide towards automated vehicles, (Carreras, et al., 2018) proposed 5 levels of infrastructure support for automated driving (ISA), based on the idea of the SAE levels for vehicle capabilities but the levels mentioned are independent and not linked to SAE levels. Figure 9 shows the description of the 5 ISAD levels, along with the information that is provided to automated vehicles.

The ISAD levels provide details on the information system and address the communication, maps, traffic signs, and road furniture aspects of the ODD as well (see Figure 9). The concept will likely be detailed further in the future and may need to be adapted and/or complemented with regards to specific automated driving use cases (Ulrich, et al., 2019).

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
	A	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

Figure 9: Levels of the Infrastructure Support for Automated Driving (ISAD levels) (Carreras, et al., 2018)

All this puts a lot of responsibility on presence of optimum and high functioning digital infrastructure as it can be seen as a minimum requirement for the highly automated and connected vehicles to function.

3.9. Impacts on planning

The introduction of automated vehicles will with most certainty be an important factor when the future transport- and traffic planning will be developed. However, there are studies which predict that the impact initially will be limited, and that in relation to other factors which affect the demand and costs for transportation. Examples of such factors are; demographic changes (aging population, driving licence, distance to work), price changes (fuel, parking, tolls), user preferences (less driving, joint ownership, means of transport), improved travel options (foot traffic, cycling, public transport, carpooling, telework, delivery services), ITS (improved information,) and planning innovations (extended goals, system solutions, demands). (Litman, 2018)

Here under are the foreseen planning consequences, according to (Litman, 2018);

2020-40 Automated vehicles will be legal, and they are becoming more common. Evaluating effects and defining requirements will be a planning focus.

2020-30 Automated vehicles will be available for people with great purchasing power, but the automated vehicles are still a minority.

2030-40 It's possible for an extensive distribution of vehicles when it comes to carpooling and taxis. However, the significance of automated vehicles for the commute journeys in peak hours are limited.

2040-50 Reduced need for conventional public transport in certain locations and reduced need for parking

2040-60 Reduction of traffic-related risks as an effect of the introduction of automated vehicles.

2050- 60 Reduced congestions and consequently less road space is required.

2060-80 Advanced traffic management is possible since automated vehicles is widespread by now.

A central issue regarding future planning is how the proportion of car sharing will increase from 0,5 % to 50-60 % of the total vehicle travel (Combined Mobility Platform, International Association of Public Transport (UITP), 2017). Questions that are mentioned as important concerning urban planning is; location and management of parking, integrated planning and prevention of urban sprawl. A focus area regarding parking is to find new ways to utilize the central areas within the city since these areas today are used for parking. When it comes to integrated planning there is of great significance to find a way to integrate mobility and urban planning. Another area for the future planning is to prevent urban sprawl and increase the overall car sharing. (International Association of Public Transport, UITP, 2017)

3.10. Impacts on active travel and health

It is certain that automation will increase overall mobility and hence enable more user groups to get on the road and travel (mostly corresponding to Level 5). This increase comes with a level of comfort which an automated vehicle provides. In some cases, it could be a natural tendency for users to prefer this 'comfortable' modes of travel over active travel options (walking and bicycle).

(CARTRE, 2018) suggests that the total mileage travelled by active modes of transportation will be reduced with more adoption of automated vehicles. More sharing of automated vehicles should lead to more usage of soft modes while more private usage of

automated vehicles could mean that private vehicles are even more attractive, thus forming a lower share of soft (active) modes (CARTRE, 2018).

One of the outputs form the workshop which corresponded to all the stakeholder groups was that automation will have a negative impact on active travel with people using more of soft means of transportation available with autonomous features over walking and biking simply because of more convenience as the main factor (EU EIP Activity 4.2, 2019). However, it was said that accessibility to better health services will increase with more AVs increasing the mobility of people making it easier for them to travel/commuter to get access to health services.

3.11. Impacts on cyber security

Cybersecurity is a growing worldwide concern. Over the recent years, much focus has been placed on critical infrastructure providers and their ability to implement cybersecurity measures in order to continue providing critical services. Highly automated vehicles, Traffic management centers (TMCs) and intelligent transportation systems (ITS) infrastructure are increasingly exposed to the Internet, thus increasing the risk of cyber threats to these transportation facilities and infrastructure.

The multitude of data which is provided and exchanged between the infrastructure and the vehicles poses additional challenges on cyber security for road operators (Carreras, et al., 2018).

During the EIP activity 4.2 workshop in Turin, cyber security was found to get relatively changed from what it looks today. There will be an increased risk of negative impact simply due to more systems getting connected which opens us more possibilities of cyber-attack (EU EIP Activity 4.2, 2019). As more things find their way to get more connected in the connected and automated environment, the higher the risks get.

3.12. Benefits of automation

This sub-chapter mentions some conclusions that can be drawn on benefits of automation.

Connected and automated driving promises to revolutionise individual mobility within the next decade. It will offer new mobility solutions that promise to be cleaner, safer and more consumer-focussed than ever, and create new areas of business for the automotive industry.

Societal benefits of connected and automated driving include but are not restricted to reduction in fuel consumption – and with that CO_2 emissions, traffic becoming even safer, effective usage of roads. The levels of congestion might also be reduced however some studies think this to be optimistic. Car-connectivity and automation will also bring considerable economic gains for society at large. These developments will likely improve access to mobility for the elderly, children, people with disabilities, people who cannot drive due to temporary reasons or those who live in remote areas such as a country side.

At the same time, connected and automated driving will create new areas of business that will change traditional automotive business models. Manufacturers will become providers of innovative mobility solutions, rather than 'just' being producers of vehicles. Manufacturers and suppliers are therefore spending a big part of the €53.8 billion that the automotive industry annually invest in R&D, on connected and automated driving. (European Automobile Manufactures' Association (ACEA), 2017)

However, it is important to make a clear distinction between automation and connectivity. Both will deliver distinctively different benefits and mobility solutions for society and pose very different challenges for both the automotive industry and policymakers.

Connected vehicles can exchange information wirelessly with other vehicles and infrastructure, but also with the vehicle manufacturer or third-party service providers. Automated vehicles, on the other hand, are vehicles in which at least some aspects of safety-critical control functions occur without direct driver or external input.

Automation and connectivity are clearly not the same thing. For example, an automated vehicle will/may not use data received from other vehicles or from the infrastructure to make decisions about steering or braking. However, automation and connectivity are complementary and will reinforce each other in the medium to long term. (European Automobile Manufactures' Association (ACEA), 2017)

A summary of the benefits identifies and mentioned in the other impacts sub-chapters can be as mentioned below:

- **Congestion mitigation:** Automated driving likely frees up spaces on the road; at an early stage of the implementation phase, automated vehicles may increase the

congestion but with more and more connectivity, improved sensing and dedicated policies congestion could reduce.

Shared vehicle fleets free up a significant amount of space in the city. However, prior experience indicates that this space must be pro-actively managed in order to lock in benefits (Manuel Viegas & M. Martinez, 2017). Management strategies could include reallocating this space to wider sidewalks, bicycle paths or delivery bays, or in some cases even to new construction of public facilities missing in the neighbourhood. For example, freed-up space in off-street parking could be used for logistics distribution centers.

Deployment of shared fleets in an urban context will directly compete with the way in which taxi and public transport services are currently organized. The higher quality of service to the user and higher efficiency in the use of public space argue in favor of this becoming the new paradigm of public transport. Public governance of transport services, as well as current operators of bus and taxis must adapt, and others will enter the market. However, congestion could also increase, unless shared automated vehicle use is promoted by other policy tools, such as provision of dedicated lanes, streets and areas for shared automated vehicles or dynamic road user charging allocating higher charges for non-shared vehicles.

- **Increased traffic safety**: A significant reduction of road accident fatalities and crashes is expected as early as 2030 (Alessandrini, et al., 2015). On the other hand, it may also happen that the road safety in a mixed traffic including both manually and automatically driven vehicles will not improve. In such a case, additional measures such as lowering of speed limits or separation of automated vehicles from human-operated ones could to be taken.
- **Increased road capacity and reduced costs**: More efficient vehicle traffic may reduce congestion and roadway costs. Reduced number of on-road vehicles via ride sharing or car sharing of automated vehicles would play a vital role in road capacity (Chan, 2017).

  Savings in terms of fuel consumption can be expected, significant results are expected later, more likely from 2050 (Alessandrini, et al., 2015).
- **Richer data for traffic and asset management:** More effective real-time navigation, trip assignment, and dynamic routing will take place, if data from connected and automated vehicles are shared with road operators and traffic managers.
- **Efficient usage of Infrastructure:** Smarter road (intelligent freeway merging, smarter squares/roundabouts) together with Smart Traffic and C-ITS Automation in mobility would bring in more benefits in the long run (Chan, 2017). More savings of resources are needed for infrastructure, including parking and roadway constructions. It can also be pointed out that with better vehicle control and coordinated operations, the infrastructure can be made more efficient for example with Automated Valet Parking and corresponding services.
- **Traffic flow smoothing**: Through the shorter distances (in longitudinal and also transversal direction) between AV when driving on the road the capacity of roads could

increase. AVs can even accelerate and decelerate in a coordinated way to prevent shockwaves. Mixed traffic might require dedicated lanes for optimal traffic smoothing.

- **Affordable and more accessible Mobility**: More affordable mobility services and less subsidized transit operations for public agencies may result from automated vehicles despite the higher costs to produce and maintain an automated vehicle in comparison to a human-operated one.
  Mobility is also set to get more accessible and shall bring new user groups into picture. People with disabilities, handicapped, children without driving license and any other group of people who can't drive can have access to traveling through AVs.

4. Costs of automation

The increased benefits for every level of automation comes with increased costs from the complexity of automation. It is very difficult to predict the exact numbers and figures for the costs involved at the moment. But as can be derived from adoption of other newer technologies, the costs involved get lower with more significant adoption of the technology. The cost-benefit relation further plays a vital role in moving forward in pushing the adoption of technology.

It is important to note that there is no clear indication about how these costs will be divided between road operators and other actors (OEM's, technology providers, users etc.). This section mentions costs of automation as a whole, including costs for technology, services offered, infrastructure as well as vehicle. It is obvious that cost of vehicles and cost of advancement of automation related technology will not lie on road operators, other costs like infrastructure (Digital and Physical), service offering related costs (ODDs and Digital maps) etc. may or may not be shared between road operators and other actors, including users in some case (through toll or paid services etc.).

There are many different types of costs that are associated with highly automated driving and automated driving in general. These costs could be on a societal, capital, maintenance and operations levels.

Litman (Litman, 2018) lists the societal level costs as:

- **Additional risks.** Automation may increase risks to other road users and may be used for criminal activities. To counter such malicious activities there will be a need to have high cyber security requirement which then comes at a cost.
- **Increased traffic problems**. Increased vehicle travel may increase congestion, pollution and sprawl-related costs.
- **Social equity concerns.** Automation may reduce affordable mobility options including walking, bicycling and transit services.
- **Reduced employment.** Jobs for drivers may decline. Although that will mean less costs for road operators who hire drivers for their transport services.
- **Increased infrastructure costs.** May require higher roadway design and maintenance standards and additional requirements for facilities and services.
- **Reduced support for other solutions**. Optimistic predictions of autonomous driving may discourage other transport improvements and management strategies.

Other costs typically include capital, maintenance and operating costs. The most important KPIs for automated road transport overall were the following (Kuisma & Innamaa, 2018)

- Capital cost per vehicle for the deployed system (infrastructure, monetary value)
- Cost of purchased automated vehicle (market price, monetary value)

- Operating costs for the deployed system (per vehicle-hour or per vehicle-km, monetary value)

For the higher level of automation (L4 - L5) the following costs were the most important ones (Kuisma & Innamaa, 2018):

- Cost per trip (for user, monetary value)
- Operation and maintenance cost for digital infrastructure (per road km, monetary value)
- Investment cost for connectivity network (per road km, monetary value)

In addition to the ones selected by (Kuisma & Innamaa, 2018), and through other literature findings, workshops and other projects like MANTRA (Penttinen, et al., 2019), etc. Following are the factors that account for the costs which are relevant for this report:

- Cost of enforcement
- Cost of cyber security
- Cost for investment of new infrastructure (both physical and digital)
- Cost for rebuilding existing infrastructure
- Cost for maintenance of digital and physical infrastructure
- Cost of accidents
- Cost of operations for road operators

AVs may require higher roadway maintenance standards, such as clearer line painting and special traffic signals (Lawson, 2018). Their impacts on overall congestion, energy, emissions and crash costs will depend on how self-driving technologies affect total travel and urban development patterns (Litman, 2018).

The highest costs for the infrastructure result from the need to provide the necessary operational design domain ODD for the automated vehicles. The unit costs for the deployment, operation and maintenance of the different ODD attributes are indicated in Table 6 according to the MANTRA project (Ulrich, et al., 2020).

Table 6: Unit deployment costs and annual maintenance cost percentages out of deployment costs for the different ODD features in 2020 (Ulrich, et al. 2020).

ODD attribute	Detailed feature	Unit cost range estimate (deployment)	Operations & Maintenance annually
Shoulder or kerb	Safe "harbours" (broad shoulders, lay-bys etc.)	20-50 k€/safe harbour; or 40-100 k€/km on sections where needed (every 500m)	8 %
	Passenger pick-up/drop-off point (markings, bench, shelter)	2-5 k€/point depending on level of services	10 %
Markings and signs	enhanced maintenance of road markings and traffic signs & signals	0.1-0.2 k€/km/a (k€/km/annum)	included
Road furniture	Landmarks for positioning enhancement	4-6 k€/km (where needed)	10 %
	Signs and/or barriers for access control	30-90 k€/sign; 40-80 k€/gate or barrier; 15-90 k€/km	8 %
	Game fences	20-30 k€/km (both sides of road)	2 %
Traffic management	Standardized marking and efficient management of road works zones, incident/event sites, and toll plazas/gates	3-5 k€/km/a	included
	Adaptation of traffic centres, systems and services to automated driving (all use cases)	10-90 k€/km	8 %
Maintenance	Enhanced snow-removal	winter maintenance cost addition: ca 2-2.5 k€/km /a (2-lane roads) and 3-4 k€/km/a (motorways)	included

ODD attribute	Detailed feature	Unit cost range estimate (deployment)	Operations & Maintenance annually
HD map non-LIDAR	HD Maps or road areas, infra, equipment	3-4 k€/km	8 %
	HD Maps of road structures for maintenance purposes	5-7 k€/km	8 %
	Road areas & environment for camera, radar, ultrasound sensors	1-3 k€/km/a	included
HD map LIDAR	Road areas & environment with LIDAR point clouds	3-6 k€/km/a (paid by the transport operator)	included
RTK stations	Satellite positioning enhancement with land stations	RTK station 2-10 k€ (depending on the availability of power); 1 station / 5 km; cost 0.4-2 k€/km	8 %
Longer range V2I	Base station (micro or macro)	35-40 k€/station/a (macro) 8-10 k€/station/a (micro)	included
Short range V2I	Roadside station	15 k€/km	8%
	Connecting to trunk communication network and servers	fibre optics 20 - 100 k€/km including outtakes	8 %
Problem info and regulation info	High quality real-time situational picture & rules and regulations	0.4-0.8 k€/km/a incl. digitalisation of rules & regulations, back-office; urban 0.1-0.2 k€/km	included

ODD attribute	Detailed feature	Unit cost range estimate (deployment)	Operations & Maintenance annually
Road works information	VMS/C-ITS warnings: road works, automated road works or maintenance vehicles	0.5-0.9 k€/km/a without new VMS but incl. equipment and marking of road work sites; road works only: 50% of costs	included

Standardization and mass markets will likely reduce the costs for roadside stations, land marks, pick-up/drop-off site equipment. The other costs will likely remain on similar levels as today.

MANTRA (Ulrich, et al., 2020) summarizes unit costs for various infrastructure changes proposed, the largest costs per road km are due to:

- Provision of safe harbours (in case of ODD termination)
- Signs and barriers for access control (in the special cases where needed)
- Adaptation of traffic centres and systems
- Up-to-date HD maps
- Trunk communications with fibre optics cabling
- Game fences alongside roads

There are also some other costs which are more specific to an automated system or a use case. MANTRA (Ulrich, et al., 2020) mentions some of such costs will be in the following areas.

- Robot taxis and automated public transport shuttles will require safe passenger pick-up and drop-off spaces by the kerb, resulting in the need to reserve such spaces and also to equip at least the most important ones of them with e.g. shelters and seats to accommodate the waiting passengers.
- To enhance the accuracy of positioning of the vehicle on road sections where the coverage of GPS signal is poor (tunnels or street canyons), fixed landmarks equipped with sensory reflectors or radio beacons on such road sections could be highly beneficial and even critical for some services. The cost for equipping such landmarks are considered to be not that significant.
- The information system is a very important part of the digital infrastructure. Real-time event and incident information of good quality is needed to provide the extended horizon to the highly automated vehicle beyond the line of sight of its sensors. Such information may be provided directly to the service providers and

vehicles or via a national access point. At the same time the vehicle needs to be aware of the rules and regulations applying to the road sections that it is using and approaching. The digital traffic regulations can be disseminated directly to vehicles and/or service providers may be organised to be delivered via a specific Trusted Digital Regulations Access Point to service and HD map providers. The implementation, maintenance, and operation of good quality information system and related access points and dissemination channels will require considerable resources.

- Establishing, maintaining and operating the communications between the infrastructure and vehicles will also be quite costly, especially the provision of the trunk communications of the roadside stations and cellular base stations.
- Traffic management – This is especially needed to deal with events and incidents so that the automated vehicles can easily navigate their way through road work zones, event-affected sections, and incident sites. Requirements are harmonized traffic management processes, plans, signs, road furniture, and markings. At the same time, the whole traffic management system needs to be digitalized.
- Infrastructure maintenance – Enhanced winter maintenance is needed for instance to ensure that road markings and signs are visible and machine-readable, and road maintenance to react to appearance of roadbed damages and potholes, or to maintain the safe refuges and passenger pick-up and drop-off areas.
- Fleet supervision – Evidently, road haulage companies and taxi companies need to have a fleet management centre also in the case of highly automated vehicle fleets. The problems related to sudden ODD termination due to heavy rain, unreported incidents, and other reasons will pause the provision of the transport service, unless the fleet management centre can also remotely supervise the vehicle to retain the ODD or to manually operate the vehicle to a location with ODD.

5. Impacts of various CAV systems

In this section a variety of automated vehicles systems are presented and their impacts from a road operator point of view is discussed. The systems have been selected based on the literature as well as on discussions within the EU EIP 4.2 task group responsible for this report. The basis of the discussion is what systems that are expected to have an impact within the foreseeable future.

5.1. Cooperative Adaptive Cruise Control (CACC)

Adding vehicle-to-vehicle (V2V) communications to an adaptive cruise control (ACC) system turns it into a Cooperative ACC (CACC) system. The idea behind CACC is not only to have a vehicle's cruise control system maintain a proper following distance behind another car by slowing down once it gets too close, (ACC), but also to allow cars to "cooperate" by communicating with each other while in the adaptive cruise control mode. The result is that cars can follow more closely, accurately, and safely, with braking and accelerating done cooperatively and synchronously. Experiments with four CACC vehicles showed the great improvement in car following stability compared to the same four vehicles using their production ACC controllers without V2V cooperation. (California Partners for Advanced Transportation Technology (PATH), University of California, Berkeley, 2018)

At the heart of each CACC concept is the merging of Adaptive Cruise Control (ACC), a subset of the broader class of automated speed control systems, with a cooperative element, such a Vehicle-to-Vehicle (V2V) or Infrastructure-to-Vehicle (I2V) communication. The V2V communication could provide information about the vehicle or vehicles directly in front, and the I2V communication could provide information about traffic further ahead or about current speed restrictions as part of an active traffic management approach.

There are two primary transportation system motivations for the development of CACC. The first motivation is to reduce traffic congestion and the second is to improve fuel efficiency. It may also improve safety, although it is not primarily a safety system. At the individual driver level, CACC can make ACC more attractive and convenient to drivers by providing behavior that is more responsive to preceding vehicle speed changes, that gives an enhanced sense of safety because of its quicker response, and that deters cut-ins at shorter gaps. (Shladover, et al., 2014)

The other motivation for the development of CACC is to improve highway and roadway capacity and throughput. The class of CACC systems utilizing V2V communication could allow the mean following time gap to be reduced from about 1.4 seconds when driving manually to on the order of 0.6 seconds when using CACC (Nowakowski, et al., 2010) and (Nowakowski, et al., 2010), resulting in an increase in highway lane capacity.

5.2. Truck Platooning

Truck platooning is the linking of two or more trucks in convoy, using connective technology and automated driving support systems. These vehicles automatically maintain a set, close distance between each other when they are connected for certain parts of a journey, for instance on motorways. The truck at the head of the platoon acts as the leader, with the vehicles behind reacting and adapting to changes in its movement – requiring little to no action from drivers. In the first instance, drivers will remain in control at all times, so they can also decide to leave the platoon and drive independently. (European Automobile Manufactures' Association (ACEA), 2017)

Truck platooning can be described as CACC but exclusively for trucks on highways in which trucks are led by a lead/pilot truck while the trucks behind drive in close proximity benefiting from drafting, resulting in better fuel economy and decreased environmental impacts. While in CACC only provides longitudinal control, leaving the driver to remain responsible for active steering control and for the active monitoring of the driving environment. The concept of truck platooning has generally included a system capable of both lateral and longitudinal control. (Nowakowski, et al., 2015)

With the following trucks braking immediately, with zero reaction time, platooning can improve traffic safety. Platooning is also a cost-saver as the trucks drive close together at a constant speed. This means lower fuel consumption and less CO_2 emissions. And, lastly, platooning efficiently boosts traffic flows thereby reducing tail-backs. Meanwhile the short distance between vehicles means less space taken up on the road. (European Truck Platooning, 2016)

One of the drawbacks could be the less space between the trucks hindering a car to change lanes while the distance between the trucks is too small while platooning.

As planned in the EU roadmap, the first step of introduction of platooning happens with the Mono-brand platooning (Trucks from the same brand for a platoon), followed by Multi-brand platooning (up to SAE level 2) with the driver still ready to intervene. The third step is making it possible for the driver of the trailing truck to rest before finally moving to full autonomous trucks (starting with driver in the lead truck). (European Automobile Manufactures' Association (ACEA), 2017)

As reported in the roadmap of (European Automobile Manufactures' Association (ACEA), 2017), by 2023, it should be possible to drive across Europe on motorways (thus crossing national borders) with multi-brand platoons, without needing any specific exemptions (See Figure 10). Subsequently, allowing the driver of a trailing truck to rest might come under consideration. Full autonomous trucks will only come later. This would need new traffic

regulations to allow the trucks to drive closer than it is allowed currently which partially be a benefit from improving technology.

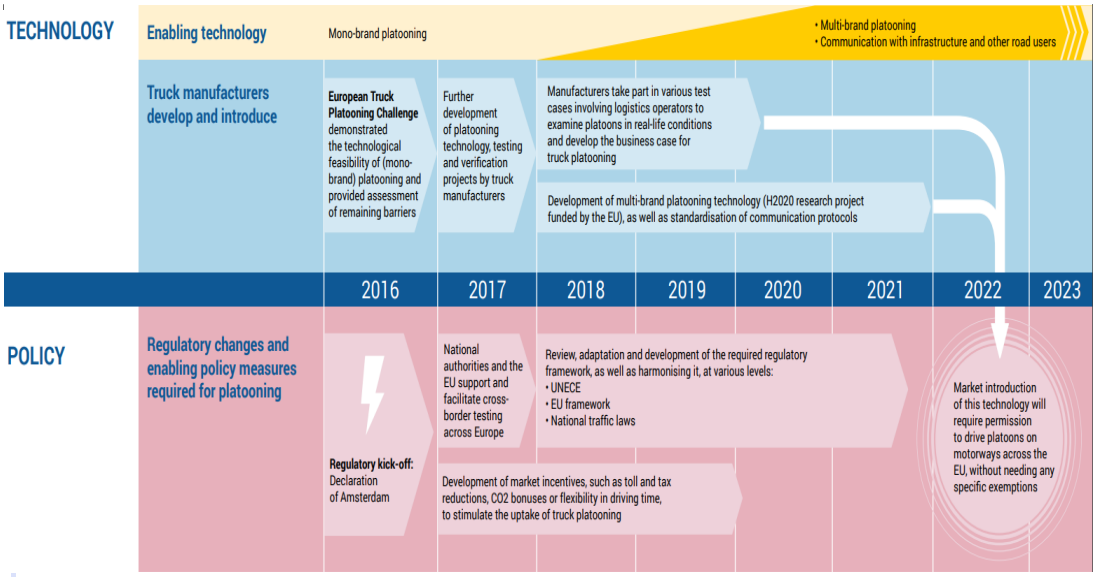

Figure 10: EU Roadmap for Truck Platooning (European Automobile Manufactures' Association (ACEA), 2017)

(European Automobile Manufactures' Association (ACEA), 2017) also points out the need to create an enabling regulatory framework at both the EU and international levels. The changes which needs to be made to existing rules and legislation, to support this framework are mentioned in Appendix 9.3: Regulatory framework to promote truck platooning in EU.

5.3. Highway pilot

Highway Pilot is a highly intelligent network consisting of assistance and connectivity systems which enables autonomous driving on the highway. It never gets tired and reacts faster than any human. It is marketed as 'the ideal companion on long journeys on highways'. (Daimler, 2018). The systems are being developed by many automotive technology providers like Bosch, Continental, AVL to name a few that aims to provide fully automated driving in production vehicles in certain ODD for e.g. motorways. (Continental AG, 2017)

Currently, the manufacturers are developing Highway Pilot for applications in both cars and trucks. Daimler are working with using Highway Pilot as a part of Platooning with

connected trucks, Highway Pilot is self-sufficient and reliant on any other vehicles or control centres but gives a possibility off achieving more by adding connectivity as a medium.

To make all this possible, Highway Pilot constantly detects the situation in the traffic environment by means of various cameras. These recognize everything that stands out against the background: roadways, pedestrians, moving and immobile objects. Furthermore, information from traffic signs is recorded.

The data from all cameras and sensors are forwarded to the vehicle systems and linked to one another. The Highway Pilot can therefore precisely determine the space between the "disruptive objects". On the basis of this data, the system regulates the steering, increases or decreases the vehicle's speed. (Daimler, 2018)

The impacts of Highway Pilot are in line with the impacts of CACC or Truck Platooning, being a core constituent of such technologies, HP makes it possible to enable the V2X communications as a result making it possible to add services with more connectivity.

5.4. Automated shuttles

Automated shuttles have now started appearing in quite a few metropolitans alongside other public transport options. Automated shuttles can find their application in first/last mile of traveller's journey but can expand to other applications with more automation. The last mile in a public transport trip is known to bring a large disutility for passengers, as the conventional transport modes for this stage of the trip can, in many cases, be rather slow, inflexible and are not able to provide a seamless experience to the passengers (Scheltes & Homem de Almeida Correia, 2017). Wang and Odoni, (Wang & Odoni, 2014) indicate that the last mile is one of the main deterrents in public transport in order to be competitive with the car.

Since a large part of the operational costs for busses in public transport is related to driver salaries, the cost for operation can be reduced radically with automated vehicles. This opens for new possibilities to improve public transport services, for instance with the use of smaller vehicles, like shuttles, to increase flexibility and service in certain areas (Pernestål Brenden & Kottenhof, 2018).

In a study, (Pernestål Brenden & Kottenhof, 2018) suggests several applications for automated shuttles in public transport. The shuttles could serve as feeders from less dense areas, such as neighbourhoods, to mass public transport. They could also serve cross connection transportation between high capacity lines. Another application is to replace the ends of high capacity lines with shuttles to make the system more efficient (usually a train or metro are crowded in the middle part of the line and not at its ends). Automated

shuttles could also be used within crowded city centres instead of large busses that are space demanding.

Furthermore, in comparison to conventional busses automated shuttles are quiet since they are electric and operates in low speeds which promotes safety in residential areas where there are many people around the road. Therefore, shuttles could be a good solution for providing transport in areas where a conventional bus is considered inappropriate for e.g.: neighbourhood near a school. Other application areas for shuttle services are hospitals, campuses, resorts or airports (Hökars, 2019).

The automated shuttles on the market today are mainly adopted to transport between 4 – 11 passengers sitting or up to 20 passengers standing. These shuttles run on electrical power and has a maximum speed of 45 km/h (Pessaro, 2016). However, the average operating speed tend to be lower. Usually around 12 km/h up to 20 km/h (Ainsalu, et al., 2018). The operational speed for autonomous shuttles is dependent on the degree of separation from other traffic. Since autonomous shuttles is programmed in a conservative manner to avoid accidents the operational speed in mixed traffic tend to be low. Separated lines or infrastructure that prioritize the autonomous shuttles can increase operational speed (Pernestål Brenden & Kottenhof, 2018).

Some automated shuttles are provided with three different operation modes; metro, bus and on demand mode. In the metro mode the shuttle stops at every stop at the route. In bus mode the shuttle only stops if a passenger requested it to stop. In the on-demand mode the shuttle can be called at through a smartphone application (Pessaro, 2016).

Various kinds of sensors, such as GNSS, camera and LiDAR sensors, enables the automated shuttle to feel, visualize and predict the surrounding environment. At present, the autonomous shuttles demonstrate an early example of level 4 automation. This is possible since the shuttles operates on pre-programmed routes in low speeds. Before an automated shuttle can operate a virtual rail and 3D map needs to be created. This is done by letting the shuttle slowly drive along a predefined route to register the surrounding elements with its sensors. Data collected from the sensors is then processed manually in order to create a place specific 3D model, which the shuttle can use when in operation to determine its position along the route (S3, n.d.).

One key factor for successful introduction of automated vehicles in public transport is user acceptance. One of the findings from a study of user acceptance of automated shuttles in Berlin indicate that the respondents were positive towards automated shuttles and could envision their use as feeders to public transport systems, in both urban and rural areas (Nordhoff, et al., 2018). In an automated shuttle pilot called CityMobil2 data on passenger's opinions were collected. Most of the passengers had a positive attitude towards automated shuttles as a complement to public transport. The potential to reduce ticket prices was

considered as one important factor. The main concern regarded people's safety during nights and off-peak hours (Alessandrini, 2016).

5.5. Automated Valet parking (AVP)

Major improvements in autonomous driving allow the realization of Automated Valet Parking (AVP). AVP enables the vehicle to drive to a parking spot and park itself. AVP, developed by Bosch in cooperation with Daimler, is a driverless system which finds a free space in the parking garage and parks the car itself by means of connected technology. (Bosch, 2018).

Driverless parking and vehicle collection allow for better utilization of parking garage capacity. Automated Valet Parking (AVP) ensures that cars park closer together, allowing for as much as a 20 percent increase in the number of vehicles that can be accommodated in the same space. (Bosch, 2018) Precise automated guidance eliminates the risk of damage to infrastructure due to careless driving. AVP opens up a range of potential service offerings: the time a driver is away from the vehicle can be efficiently used for car washing or windshield replacement.

In a AVP system developed by Bosch, for drivers, all it takes to use AVP is the touch of a button within the smartphone app: this establishes the digital connection between the parking garage and the drop-off area so that the route to the next available parking space can be calculated (See Figure 11 for visualization). Parking spaces are selected based on the size of the vehicle, then the Bosch technology within the parking garage takes over. This includes cameras that identify suitably sized vacant parking spaces and then monitor the vehicle as it progresses, detecting any surprise obstacles or pedestrians on the vehicle's path so that it can react immediately. Once it has reached its destination, the vehicle parks itself fully automatically, even when space is tight. The process works exactly the same in reverse: the driver summons the vehicle back via the app and can then get in and drive off straightaway. (Bosch, 2018)

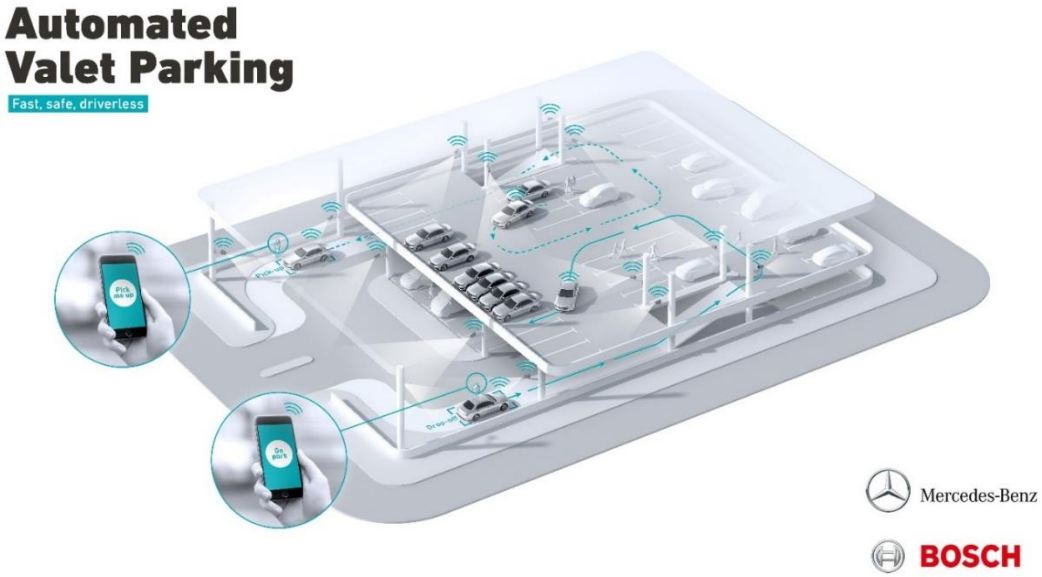

Figure 11: Visualization of AVP by Bosch

5.6. Robo-Taxi

AVs could play a key role in the transformation of mobility or how people commute. But the industry tends to view the phenomenon mainly through a technology lens, which, while important, only addresses parts of the challenge. Industry discussions often focus on autonomous-driving levels, such as the Society of Automotive Engineers' conditional, high, or full-automation specifications (SAE levels 3, 4, or 5, respectively). (McKinsey & Company, 2017)

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European ITS Platform

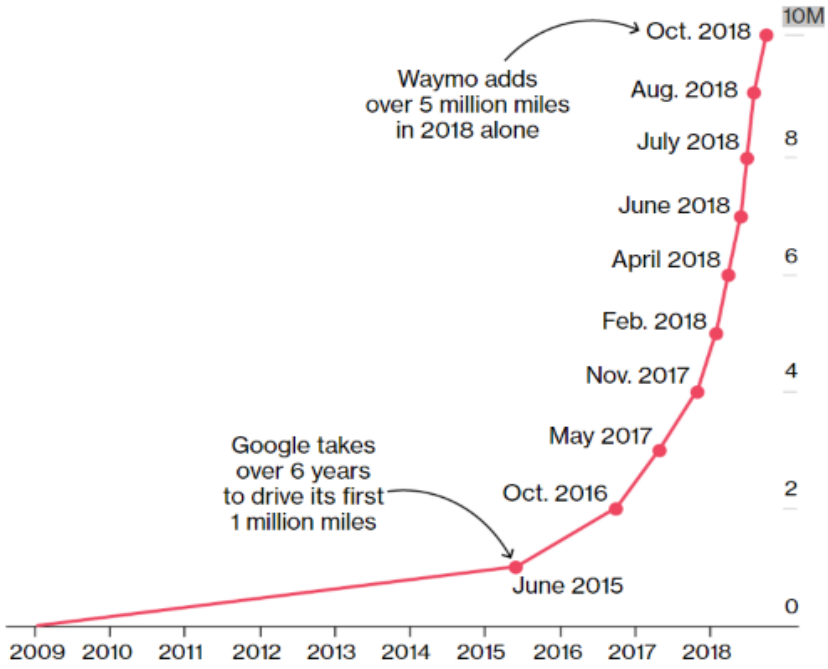

Figure 12: Driverless miles covered by Waymo's fleet (Waymo, 2018)

Waymo, subsidiary of Google's parent company, Alphabet Inc., has launched the world's first commercial driverless car service in December 2018 (Waymo, 2018). It operates as Robo-taxi/ autonomous on-demand service by the name Waymo One and currently runs in Phoenix, Arizona only with passengers from their early rider program. The company has ordered 62,000 Chrysler Pacifica vans and 20,000 Jaguar SUVs to support future deployment of autonomous shared vehicles, with deployment planned for 2019, 2020 and 2021. Waymo is "interviewing" urban areas for possible deployment, with a preference for large cities with good weather (no snow) and favourable local regulations. Uber has ordered 2,400 vehicles from Volvo and, prior to the recent fatal accident in Tempe, Arizona, expected to deploy autonomous shared vehicles in 2019, 2020, and 2021 (Welch & Behrmann, 2018).

Waymo has always been ahead of the likes of other self-driving taxi services in their testing phase, having driven more than combined 10 Million driverless miles on their fleet of cars (See Figure 12) they have a big lead over others in the market like Zoox who raised $800million in July 2018 with intention to launch their services by 2020 (CNBC, 2018).

OEMs are also developing driverless technology. GM, for example, purchased Cruise, a company that was developing a driverless vehicle. It recently announced that this technology could be integrated into its production line for the Chevy Bolt and has mentioned 2019 as a possible time to begin deployment. According to the report (Mudge,

et al., 2018) during mid-2018, Cruise received additional investments from Softbank ($2.25 billion), GM itself ($1.25 billion), and Honda Motors ($2.75 billion).

Goldman Sachs Group Inc. predicts that robo-taxis will help the ride-hailing and -sharing business grow from $5 billion in revenue today to $285 billion by 2030. There are grand hopes for this business. Without drivers, operating margins could be in the 20 percent range, more than twice what carmakers generate right now. If that kind of growth and profit come to pass—very big ifs—it would be almost three times what GM makes in a year. And that doesn't begin to count the money to be made in delivery (Welch & Behrmann, 2018).

Still, Waymo's head start isn't insurmountable. GM plans to start a similar ride-hailing service in late 2019, while Tesla, Daimler, Volkswagen and other competitors aren't far behind—each with their own approach to solving the technological and social challenges of taking human drivers out of the car. But firms such as Bloomberg (Welch & Behrmann, 2018) and McKinsey (McKinsey & Company, 2017) predict that other leaders like GM are probably more than a year away from doing this which is very impressive from Waymo point of view.

Waymo's website also shows their plan to introduce the same tech as in their cars to drive commercial vehicles. Given that they have the right set of hardware at their disposal, this service can mean big deal for services in which commercial vehicles play a big part for example; urban logistics. However, Waymo has not revealed more of their intensions with their service for commercial vehicles.

The service Robo-taxi is too new to see its true impacts on driving externalities, as with other technology adoption process, we are in the early adoption stage and while the tech has a long way to go for being flawless and trustworthy by majority. The service can increase the traffic through increased ridership which also includes addition of new riders which were not contributing to road traffic before. (Discussed more in the discussion)

6. Discussion

This report is focused on a broad overview of the literature, current trends in mobility, use cases, identified impacts of automation and CAV systems. During the various phases of the task, there were some discussion points which stood out which are mentioned below.

6.1. Bandwidth of impacts and specificity for road operators

A first conclusion from the literature is that the expected effects are often more argumentative than based on empirical studies. There is also a focus on the overall effects like traffic will increase/decrease or vehicle kilometres travelled will increase/decrease rather than specifying what this implies for the road operators. This is to a large extent due to the uncertainties about what the effects really will be. Automated driving might lead to more traffic since it is the "preferred mode of travel" for convenience and comfort, but it might also lead to less traffic since it can be an enabler for shared mobility and mobility services. The uncertainty and the wide range of potential scenarios makes it difficult to set what the costs and benefits for highly automated driving for road operators are.

To handle the uncertainties in the following phases it is important to have a close contact with the relevant stakeholder and projects to get a better idea of how they are reasoning with regard to these issues. It is also of importance to consider what the effects are based on different scenarios and what that brings in terms of cost for road operators. As a final stage one could consider which scenario(s) is (are) the most attractive from a road operator point of view, if that is in line with national targets and then consider which investments and actions would be most beneficial to increase the chance of this scenario to become a reality.

6.2. Responsibilities and costs share for road operators

As stated in Section 4 (Costs of automation), at the moment it is still unclear what costs related to automation will be taken by road operators, what costs will be shared between road operators and other players, and what costs can be entirely skipped by road operators. The key reasons behind this being lack of knowledge from real life practices due to an early state of the technology and its adoption. The automated vehicle industry is going through what can be termed as a revolution of a kind where new types of services are being offered as a result new business models are being introduced with even more vast array of stakeholders involved than the automobile industry has ever worked before.

All of this brings uncertainties into the picture, especially in terms of costs and responsibilities to be shared. The responsibilities of the costs might be closely related to

the cost-benefit relationship for each stakeholder. While the business models will make those clear, ownership of services especially the data connected to these services might be a deciding factor as well.

6.3. Ownership and operation of automated vehicles

Clearly mobility solutions are advancing rapidly. Nonetheless, driverless vehicles are expected to begin to appear in meaningful numbers within the next 5 years (2020-2024) and could achieve broader market penetration within 2030. Instead of an individual driver, these vehicles will in specific areas and conditions (operational design domain) be managed by a central controller as fleets of interchangeable vehicles that can be dispatched to serve individuals and groups of riders originating at about the same place and time going in the same general direction. This shared-ride functionality will lead to improved utilization and efficiencies, if the travellers will accept to share their journeys with others..

Importantly, these facts mean that the ownership model for such vehicles will be different from that which exists today. Use will be by many individuals rather than by a single owner. Instead of individual owners as the dominant model, a fleet owner will be more practical. Demand will be affected by pricing and service, which may well be best in moderately dense, so-called transit-oriented land uses. Person miles travelled are likely to increase, while vehicle miles travelled are likely to decrease proportional to the growth in ridesharing.

6.4. Adoption of automation of vehicles

Some studies for example (CARTRE, 2018) also show that the real benefits of CAV don't arrive until the penetration of such vehicles in the market is more than a certain number (70% according to some studies), it's only when there are certain number of CAVs on the streets and in majority, when we would see the real and core benefits of such technology.

More maintenance costs can occur. Some studies reveal that with more adoption of CAVs and the amount of people using them for travelling, there would be new users who now would see benefits of using an automated vehicle due to their ease of use. This would mean that to cater the new increased demand, there would have to be more vehicles on the road which in turn would ask for higher maintenance of the road and the infrastructure as well as the vehicles themselves.

The scenario analysis made in (CARTRE, 2018) which can be seen briefly in Figure 13 shows that in the short term (scenario where the focus was on gradual extrapolation of automated services), 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, Scenario 3, 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 (Scenario 2 and Scenario 3) showed the most benefits from automated driving. However, in scenario 4, where shared mobility was not considered to be successful, was assessed as the best one in terms of economic impacts.

	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

Figure 13: Assessment of scenarios based on the impacts they make. (CARTRE, 2018)

6.5. Use and business case of automated driving

In a report highlighting regulations around automated driving by (OECD Corporate Partnership Board, 2015), it was pointed out that the use and business cases are closely linked to the pathways adopted for automation. Incremental advances in automation in conventional vehicles are unlikely to fundamentally change vehicle market dynamics. “It seems likely that individuals will buy and own such upgraded cars much as they do today. Automated driving will be available for certain situations – for instance when driving on motorways, parking a car, or handling stop-and-go traffic in case of congestion.” (OECD Corporate Partnership Board, 2015). Because the human driver must resume active control

when prompted to do so, such conditional automation raises particularly difficult issues of human-machine interaction that have not been satisfactorily solved. Fully self-driving cars on the other hand, will not face the same issue of human-machine coordination, although their use will likely be confined to contexts where the vehicle can confidently handle the full range of driving complexity. Such highly specific contexts include particular routes and low-speed operations. Self-driving cars have a much higher potential for disruption. They may be deployed in fleet-wide systems that would fundamentally reshape individual travel and have an impact on industries such as public transport and taxis.

6.6. Importance of data sharing for benefiting the automation of vehicles

Importance of Data sharing for benefiting automated driving and corresponding services has been pointed out at various events. Many road operators believe that more open data and having access to it are the key in driving the new trends of mobility. Availability of open APIs as well as availability of privately-owned APIs is said to have greater benefits than doing all by themselves (road operators) which then also differ in quality and quantity (Proceedings European ITS Forum 2018, Utrecht).

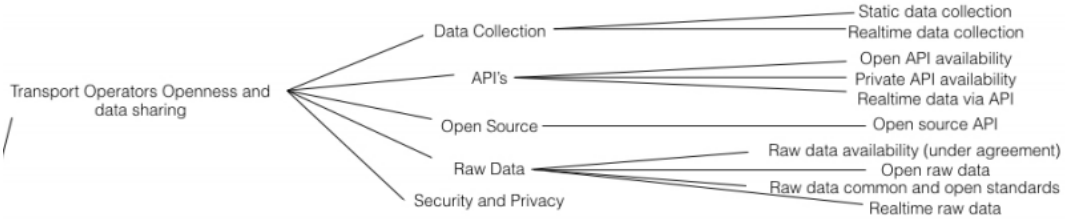

Figure 14: Dimension and sub dimensions of MaaS maturity. (Goulding & Kamargianni, 2018)

According to a study (Goulding & Kamargianni, 2018) made to formulate Mobility-as-a-Service (MaaS) maturity index, the dimensions of this index from a Transport operator's perspective as Data collection, APIs, Open source, Raw data, Security and Privacy. See figure 14 for an overview.

As for today, there are several security issues that need to be considered when automated vehicles are introduced. One example is, how will automated vehicles protect themselves from system and hardware problems, what will happen if the automated vehicle's system or hardware fails due to a cyberattack etc.

It is important to note that there will always be some barriers to implement some C-ITS services, services that require sharing of various data which the OEMs can choose to not share. This can be said about personal vehicles as well, with GDPR, users might want to not share specific type of probe data from their vehicles unless there are certain policies which enables the actors to get hold the data from every vehicle, private or part of a fleet.

7. Recommendation

The recommendations are based on both the literature and project inventory as well as the workshop and discussions within the project group.

As has been mentioned in the discussion most of the findings are based on argumentation rather than empirical studies and there is a need to launch pilots. These pilots should have both a technical and a societal focus to get a better understanding of costs and benefits. These pilots would require industrial, public and academic as well as road operator cooperation. There is also a growing discussion on infrastructure requirements to support automated driving. It is not clear yet who this responsibility belongs to or how these responsibilities will be shared between road operators and OEMs. It is recommended to use a common framework of definitions as facilitator for this discussion.

Both the literature and the workshop showed that there are potentially big benefits coming from the introduction of automated vehicles. However, similarly there are potential drawbacks to be expected as well. To be able to reap the benefits and to avoid the drawbacks there is a need to plan our transport systems accordingly and this includes amongst others physical planning, organizational issues as well as legal and financial instruments. Here more research is needed and preferably coordinated with empirical pilots. And of course this is not just a matter of fact finding and sound reasoning, but also of (vested) interests, business cases and political orientations.

When introducing automated vehicles there are costs expected to be associated with the introduction and also longer-term operation. The size of the costs is still unclear, and the costs will vary depending on what automated system is being introduced and the prerequisites at that location. Many of these costs may fall under the domain of road operators. However, the benefits may not necessarily be linked to the goals of road operators (such as safety, efficiency, environment) but can rather be reduced operating costs or increased efficiency for private actors. Here more work is needed to find business models that can accommodate for the introduction and operation of automated vehicle systems considering that the actors benefitting might not be the same as the one bearing the costs.

Data sharing is mentioned as a crucial enabler for automated systems and here more work is needed to find both safe and secure technical solutions for this as well as business models for how to share data. Several European research projects and platforms are already dealing with this and the recommendation is to continue this work on a European as well as national level. In addition, it is strongly recommended that public actors such as road operators, cities and transport organizations consider what data they have that are

useful for automated vehicles and how that data can be quality assured, updated and securely communicated to the automated vehicles and shared to other stakeholders who can use the data to provide better services to road users and road operators as well.

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9. Appendix

9.1. Project inventory

The project inventory is partly based on searching the literature but also on the knowledge and contacts of the participants within sub-activity 4.2. There is the ambition to get in contact with relevant, ongoing projects to extract information but also to get the chance to influence what they are observing to accommodate our needs.

The first step of the project inventory is to list finished and ongoing projects and their relevance for this sub-activity. For this means an Excel-template available online is used where participants in sub-activity 4.2 can enter information (see figure 9). This inventory will then be used to select projects to collect information on and, in a second iteration, decide for which projects to continue with the cost elaboration.

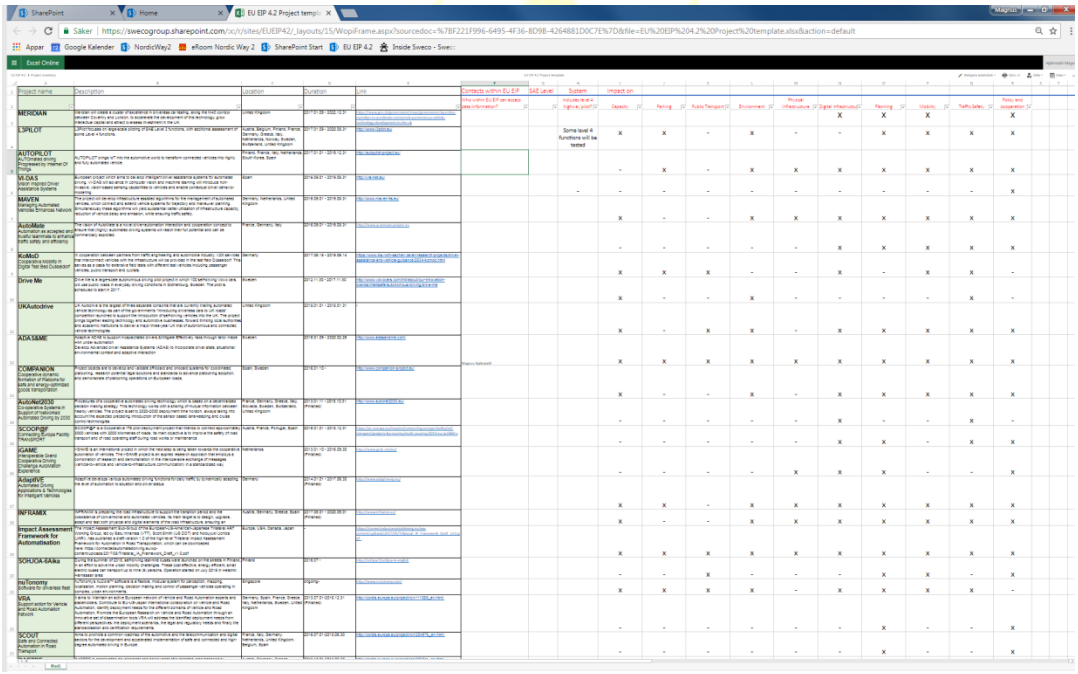

Figure 15: The on-line template used for project inven4tory.

The template has the following headings on a general level:

- Project name
- Description
- Location
- Duration
- Link
- Contacts within EU EIP (Who within EU EIP can access data/information?)
- SAE Level
- System

In addition to that there is the possibility to tick boxes for which of the clusters (effects) studied within 4.2 that the project could provide information on.

The projects included in the inventory for Phase 1 are included in Table 7 below.

Table 7 The projects included in the project inventory for phase 1.

Project name	Description	Location	Duration	Link
MERIDIAN	Meridian will create a cluster of excellence in driverless car testing, along the M40 corridor between Coventry and London, to accelerate the development of this technology, grow intellectual capital and attract overseas investment in the UK.	United Kingdom	2017.01.09 - 2022.12.31	https://www.gov.uk/government/news/government-launches-meridian-to-accelerate-connected-autonomous-vehicle-technology-development-in-the-uk
L3PILOT	L3Pilot focuses on large-scale piloting of SAE Level 3 functions, with additional assessment of some Level 4 functions.	Austria, Belgium, Finland, France, Germany, Greece, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom	2017.01.09 - 2020.08.31	http://www.l3pilot.eu/
AUTOPILOT AUTOmated driving Progressed by Internet Of Things	AUTOPILOT brings IoT into the automotive world to transform connected vehicles into highly and fully automated vehicle.	Finland, France, Italy, Netherlands, South Korea, Spain	2017.01.01 - 2019.12.31	http://autopilot-project.eu/
VI-DAS Vision Inspired Driver Assistance Systems	European project which aims to develop intelligent driver assistance systems for automated driving. VI-DAS will advance in computer vision and machine learning will introduce non-invasive, vision-based sensing capabilities to vehicles and enable contextual driver behavior modelling.	Spain	2016.09.01 - 2019.08.31 (finished)	http://vra-net.eu/
MAVEN Managing Automated Vehicles Enhances Network	The project will develop infrastructure assisted algorithms for the management of automated vehicles, which connect and extend vehicle systems for trajectory and maneuver planning. Simultaneously these algorithms will yield substantial better utilization of infrastructure capacity, reduction of vehicle delay and emission, while ensuring traffic safety.	Germany, Netherlands, United Kingdom	2016.09.01 - 2019.08.31 (finished)	http://www.maven-its.eu/
AutoMate Automation as accepted and trustful teammate to enhance traffic safety and efficiency	The vision of AutoMate is a novel driver-automation interaction and cooperation concept to ensure that (highly) automated driving systems will reach their full potential and can be commercially exploited.	France, Germany, Italy	2016.09.01 - 2019.08.31 (finished)	http://www.automate-project.eu
KoMoD Cooperative Mobility in Digital Test Bed Dusseldorf	In cooperation between partners from traffic engineering and automobile industry, V2X services that interconnect vehicles with the infrastructure will be provided in the test bed Düsseldorf. This serves as a basis for extensive field tests with different test vehicles including passenger vehicles, public transport and cyclists.	Germany	2017.06.15 - 2019.06.14 (finished)	https://www.ika.rwth-aachen.de/en/research/projects/driver-assistance-and-vehicle-guidance/2534-komod.html

Drive Me	Drive Me is a large-scale autonomous driving pilot project in which 100 self-driving Volvo cars will use public roads in everyday driving conditions in Gothenburg, Sweden. The pilot is scheduled to start in 2017.	Sweden	2012.11.30 - 2017.11.30 (finished)	http://www.volvocars.com/intl/about/our-innovation-brands/intellisafe/autonomous-driving/drive-me
UKAutodrive	UK Autodrive is the largest of three separate consortia that are currently trialling automated vehicle technology as part of the government's "Introducing driverless cars to UK roads" competition launched to support the introduction of self-driving vehicles into the UK. The project brings together leading technology and automotive businesses, forward thinking local authorities and academic institutions to deliver a major three-year UK trial of autonomous and connected vehicle technologies.	United Kingdom	2015.01.01 - 2018.01.31 (finished)	-
ADAS&ME	Adaptive ADAS to support incapacitated drivers &Mitigate Effectively risks through tailor made HMI under automation Develop Advanced driver Assistance Systems (ADAS) to incorporate driver state, situational/ environmental context and adaptive interaction	Sweden	2016.01.09 - 2020.02.29	http://www.adasandme.com/
COMPANION Cooperative dynamic formation of Platoons for safe and energy-optimized goods transportation	Project objects are to develop and validate off-board and onboard systems for coordinated platooning, research potential legal solutions and standards to advance platooning adoption, and demonstrate of platooning operations on European roads.	Spain, Sweden	2016.01.10 – (finished)	http://www.companion-project.eu/
AutoNet2030 Co-operative Systems in Support of Networked Automated Driving by 2030	Procedures of a cooperative automated driving technology which is based on a decentralized decision making strategy. This technology works with a sharing of mutual information between nearby vehicles. The project is set to 2020-2030 deployment time horizon, always taking into account the expected preceding introduction of the sensor based lane-keeping and cruise control technologies.	France, Germany, Greece, Italy, Slovakia, Sweden, Switzerland, United Kingdom	2013.01.11 - 2016.10.31 (finished)	http://www.autonet2030.eu/
SCOOP@F Connecting Europe Facility TRANSPORT	SCOOP@F is a Cooperative ITS pilot deployment project that intends to connect approximately 3000 vehicles with 2000 kilometres of roads. Its main objective is to improve the safety of road transport and of road operating staff during road works or maintenance	Austria, France, Portugal, Spain	2016.01.01 - 2018.12.31 (finished)	https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/projects-by-country/multi-country/2014-eu-ta-0669-s
iGAME Interoperable Grand Cooperative Driving Challenge AutoMation Experience	i-GAME is an international project in which the next step is being taken towards the cooperative automation of vehicles. The i-GAME project is an applied research approach that employs a combination of research and demonstration in the interoperable exchange of messages (vehicle-to-vehicle and vehicle-to-infrastructure communication) in a standardized way.	Netherlands	2013.01.10 - 2016.09.30 (finished)	http://www.gcdc.net/en/
AdaptIVE Automated Driving Applications & Technologies for Intelligent Vehicles	AdaptIVe develops various automated driving functions for daily traffic by dynamically adapting the level of automation to situation and driver status	Germany	2014.01.01 - 2017.06.30 (finished)	http://www.adaptive-ip.eu/

INFRAMIX	INFRAMIX is preparing the road infrastructure to support the transition period and the coexistence of conventional and automated vehicles. Its main target is to design, upgrade, adapt and test both physical and digital elements of the road infrastructure, ensuring an uninterrupted, predictable, safe and efficient traffic.	Austria, Germany, Greece, Spain	2017.06.01 - 2020.05.01	http://www.inframix.eu/
Impact Assessment Framework for Automatisation	The Impact Assessment Sub-Group of the European-US-American-Japanese Trilateral ART Working Group, led by Satu Innamaa (VTT), Scott Smith (US DOT) and Nobuyuki Uchida (JARI), has published a draft version 1.0 of the high-level Trilateral Impact Assessment Framework for Automation in Road Transportation, which can be downloaded here: https://connectedautomateddriving.eu/wp-content/uploads/2017/05/Trilateral_IA_Framework_Draft_v1.0.pdf	Europe, USA, Canada, Japan	-	https://connectedautomateddriving.eu/wp-content/uploads/2017/05/Trilateral_IA_Framework_Draft_v1.0.pdf
SOHJOA-6Aika	During the summer of 2016, self-driving last-mile buses were launched on the streets in Finland, in an effort to solve the urban mobility challenges. These cost effective, energy efficient, small electric buses can transport up to nine (9) persons. Operation started on July 2016 in Helsinki Hernesaari area	Finland	2016.07 -	http://sohjoa.fi/sohjoa-in-english
nuTonomy Software for driverless fleet	nuTonomy's nuCore™ software is a flexible, modular system for perception, mapping, localization, motion planning, decision making and control of passenger vehicles operating in complex, urban environments.	Singapore	ongoing-	http://www.nutonomy.com/
VRA Support action for Vehicle and Road Automation network	It aims to:• Maintain an active European network of Vehicle and Road Automation experts and stakeholders,• Contribute to EU-US-Japan international collaboration on Vehicle and Road Automation,• Identify deployment needs for the different domains of Vehicle and Road Automation,• Promote the European Research on Vehicle and Road Automation through an innovative set of dissemination tools.VRA will address the identified deployment needs from different perspectives: the deployment scenarios, the legal and regulatory needs and finally the standardization and certification requirements.	Germany, Spain, France, Greece, Italy, Netherlands, Sweden, United Kingdom	2013.07.01-2016.12.31 (Finished)	http://cordis.europa.eu/project/rcn/111089_en.html
SCOUT Safe and Connected Automation in Road Transport	Aims to promote a common roadmap of the automotive and the telecommunication and digital sectors for the development and accelerated implementation of safe and connected and high-degree automated driving in Europe.	France, Italy, Germany, Netherlands, United Kingdom, Belgium, Spain	2016.07.01-2018.06.30 (finished)	http://cordis.europa.eu/project/rcn/204978_en.html
CARTRE Coordination of Automated Road Transport Deployment for Europe	CARTRE is accelerating development and deployment of automated road transport by increasing market and policy certainties. CARTRE supports the development of clearer and more consistent policies of EU Member States in collaboration with industry players ensuring that ART systems and services are compatible on a EU level and are	Austria, Germany, Greece, Belgium, Italy, Spain, France, United Kingdom, Czech Republic,	2016.10.01-2018.09.30 (finished)	http://cordis.europa.eu/project/rcn/206011_en.html

	deployed in a coherent way across Europe.	Netherlands, Sweden, Finland		
interACT Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments	To ensure intuitive and cooperative interaction between the AV and others, and a smooth flow of all traffic, it is essential that there is good means of communication between all actors. The main objective of interACT is to substantially improve this communication and cooperation strategy. interACT will provide an overview of current human-machine interactions in mixed traffic, and increase chances of safe deployment of AVs by developing novel software and HMI hardware components for reliable and user-centric communication between an AV with its users.	Germany, Italy, Greece, United Kingdom	2017.05.01-2020.04.30	http://cordis.europa.eu/project/rcn/209718_en.html
SAFETRIP Satellite Application For Emergency handling, Traffic alerts, Road safety and Incident Prevention	SafeTRIP project's general objective is to improve the use of road transport infrastructures and to improve the alert chain (information / prevention / intervention) in case of incidents by offering an integrated system from data collection to transport safety service provision. SafeTRIP directly contributes to the achievement of the EC objectives regarding road transport safety, road mortality reduction and environment protection. SafeTRIP benefits from a new satellite technology: the S-band supported by the W2A satellite that was launched in April 2009. Opening new perspectives for European telecommunications, the S-band transmitter is optimized for content delivery and two-way communications for on-board vehicles units interoperable with Galileo and UMTS systems.	France, Germany, Poland, United Kingdom, Spain, Hungary, Italy,	2009.10.01-2013.03.31 (finished)	http://cordis.europa.eu/project/rcn/92596_en.html
Driverless vehicles: impacts on traffic flows	Research analysing the potential impacts of advanced driver assistance systems, automated and connected vehicle technologies on traffic flow and road capacity. The research consists of: •a review of existing evidence and ongoing research •modelling analysis to quantify the potential impacts in a range of scenarios	United Kingdom	Published 6 January 2017 (finished)	https://www.gov.uk/government/publications/driverless-vehicles-impacts-on-traffic-flow
UrbanAutoTest	the UrbanAutoTest project has as main objective to facilitate companies to develop and test connected and automated driving functionalities in Tampere located about 200 km north of Helsinki. The weather in Tampere is challenging in winter times due to snow, ice and slush conditions, which can change rapidly. The project has generated a test environment, consisting of closed and public route test track with test equipment, portfolio of verification and validation, technology research and consultancy services and growing portfolio of test vehicles and tools.	Finland	ongoing-	http://www.vtt.fi/sites/urbanautotest/

AutoNOMOS	The AutoNOMOS software is a modular system for the operation of autonomous or semi-autonomous cars. Using AutoNOMOS, it is be possible to detect impending dangers on roads, highways, and crossings (lane change, traffic jams, rights of way) at an early stage and accidents can be prevented. Once the technology is ready, it will be introduced at first on private property and, finally, in public traffic. The project will make a contribution to the development of accident-free, efficient, and environmentally friendly mobility	Germany	ongoing-	http://autonomos-labs.com/
LUTZ Project	As well as demonstrating autonomous vehicles, the project addressed the wider key challenge of how to increase mobility by demonstrating the potential for effective and cost-efficient movement of people in a city. The LUTZ project saw Pods deployed in the streets of Milton Keynes in October 2016 running their Selenium complete autonomy system.	United Kingdom	Finished 2016	http://ori.ox.ac.uk/projects/lutz-self-driving-pods/
SNUber	Automated driving project at the national university of Seoul.	Korea	ongoing-	http://vi.snu.ac.kr/xe/
interactIVE Accident avoidance by active intervention for intelligent vehicles	Development of safety systems supporting the driver (joint steering and braking actuators)	Czech Republic, Germany, Spain, Finland, France, Greece; Italy, Netherlands, Sweden, United Kingdom	2010.01.01 – 2013.11.30 (finished)	http://www.interactive-ip.eu/
DRIVE2X DRIVing implementation and Evaluation of C2X communication technology in Europe	Creation of harmonized Europe-wide testing environment for cooperative systems, promotion of cooperative driving	Germany, Austria, Belgium, Spain, Finland, France, Italy, Netherlands, Romania, Sweden, United Kingdom	2011.01.01 – 2014.07.31 (finished)	https://cordis.europa.eu/project/rcn/97464_en.html
FOTsis European Field Operational Test on Safe, Intelligent and Sustainable Road Operation	Intelligent transport systems, electronic stability control, cooperative I2V & V2I technologies, emergency management, safety incident management, intelligent congestion control, dynamic route planning, infrastructure safety assessment	Spain, Austria, Belgium, Germany, Finland, France, Greece, Poland, Portugal	2011.04.01 – 2015.03.31 (finished)	https://cordis.europa.eu/project/rcn/98318_en.html
DENSE Adverse weather environmental sensing system	The project aims to develop and validate an all-weather sensor suit for traffic services, driver assistance and automated driving	Germany, Sweden, France, Netherlands, Finland, Belgium	2016.03.01 – 2019.05.31 (finished)	https://www.dense247.eu/home/
CONCORDA Connected Corridor for Driving Automation	The project contributes to the preparation of European motorways for automated driving and high density truck platooning. The main objective of the project is to assess the performance of hybrid communication systems, combining	Austria, France, Germany, Greece, Italy, Nettherlands, Spain	2017.10.01 – 2020.06.01	http://erticonetwork.com/new-project-driving-automation-kick-off-brussels/

	802.11p and LTE connectivity, under real traffic situations			
AURORA ARCTIC CHALLENGE (NordicWay2)	The Finnish Transport Agency and the Finnish Transport Safety Agency Trafi are carrying out the Arctic Challenge, a project examining opportunities in road transport automation and intelligent infrastructure and their performance in snowy and icy conditions. The functionality of the proposed solutions has to be verified through field studies carried out using automated vehicles. Studies are carried out on the Aurora intelligent highway in Lapland (E8).	Highway E8, Finland. Intelligent road 10 km Pahtonen - Muonio.	September 2017 - December 2020	https://www.liikennevirasto.fi/web/en/e8-aurora/r-d/arctic-challenge#.Wt2uXBFlLIU
Autopiloten	The aim of the Autopiloten project is to accumulate knowledge about how autonomous technology can play a part in the development of public transport. It should be possible to use the type of bus being tested as a complement to other public transport. It could open for truly door-to-door solutions that link the journey together and make public transport as a whole more attractive	Kista, Stockholm	2018.01.24 – July 2018 (finished)	http://www.nobina.com/en/press/archive/10000-passengers-have-tried-autonomous-bus-service/
C-ROADS Germany (Connected Roads Germany)	Eight so called Day One Services, which shall be supported by the basic system at the time of C-ITS market introduction, are trailled in the German test fields in Hessen (DRIVE-test field Hessen for connected automated traffic around Frankfurt) and Niedersachsen (Test field Lower Saxony). The national pilots contribute their implementation framework and experiences to the super-ordinated C-ROADS Platform, with the goal of implementing, providing and harmonising cooperative intelligent transport systems and services (C-ITS) on European roads.	Germany (Lower Saxony and Hessen)	February 2016 – December 2020	"https://www.c-roads.eu/platform.html www.c-roads-germany.de"
C-ITS Corridor (Cooperative Intelligent Transport System Corridor)	The roadside cooperative ITS infrastructure for the initial services in the Cooperative ITS Corridor Rotterdam – Frankfurt/M. – Vienna will be installed. The EU Member States the Netherlands, Germany and Austria have signed a Memorandum of Understanding to realise this new technology in close cooperation. The deployment of the corridor has been agreed with industry, that they will also bring vehicles and telematic infrastructure onto the market. Declarations of intent were already signed by the parties involved or are in preparation. Two cooperative ITS services are first planned for use in the Cooperative ITS Corridor Rotterdam – Frankfurt/M. – Vienna: Roadworks warning and vehicle data communication for improved traffic management.	Germany; Netherlands, Aus´tria	November 2013 – December 2012 (finished)	http://c-its-korridor.de/
aFAS (Automatisch fahrerlos fahrendes Absicherungsfahrzeug für Arbeitsstellen auf Autobahnen)	In the Project aFAS, a driverless safeguarding vehicle, safeguarding mobile short term road works automatically, will be developed and tested under real conditions. The project studies the technical feasibility and legal aspects of a driverless and fully automated vehicle on the road (SAE level 4).	Germany	August 2014 – June 2018 (finished)	https://www.afas-online.de/

Providentia		Germany	December 2016 – June 2019 (finished)	http://testfeld-a9.de/projekt/
ConVeX	Connected Vehicle (V2X) of Tomorrow	Germany	December 2016 – June 2019 (finished)	
KO-HAF (kooperatives, hochautomatisiertes Fahren)	The objective of Ko-HAF is the next significant step towards autonomous driving, the highly automated driving at higher speeds. These next-generation systems are characterized by the fact that the driver does not need to monitor the system permanently. However, the driver must be able to take over the control of the vehicle within a certain time reserve. For this purpose, forecasts for environment detection and the automation of the longitudinal and lateral control of the vehicle have to be improved. Within Ko-HAF a so-called Safety Server as back-end solution will be developed. The vehicles of different partners communicate via mobile with this Safety Server and apply the environmental performance of their own onboard sensors (e.g. quality of markings) in. At the Safety Server, this information is collected, evaluated and compressed, so a digital map can be provided to vehicles which has the foresight range invoice required for highly automated driving. Furthermore, the system will be tested under virtual conditions and also implemented into some test vehicles.	Germany	June 2015 – November 2018 (Finished)	https://www.ko-haf.de/startseite/
IMAGiNE (Intelligente Manöver Automatisierung - kooperative Gefahrenvermeidung in Echtzeit)	The IMAGinE (Intelligent Maneuver Automation – cooperative hazard avoidance in realtime) project is developing innovative driving assistance systems for cooperative driving. Cooperative driving refers to road traffic behaviour in which road users cooperatively plan and execute driving maneuvers. Individual driving behaviour is coordinated with other road users and the overall traffic situation based on automatic information exchange between vehicles and infrastructure. Critical situations can be avoided or mitigated, thereby making driving safer and more efficient.	Germany	September 2016 – August 2020	https://www.imagine-online.de
MANTRA (Making full use of Automation for National Transport and Road Authorities – NRA Core Business)	MANTRA responds to the questions posed as CEDR (Conference of European Directors of Roads) Automation Call 2017 Topic A: How will automation change the core business of NRA's (National Road Authorities).	Austria Finland Germany	September 2018 – August 2020	https://www.cedr.eu/wpfb-file/mantra-pdf/

9.2. Proceedings from Torino workshop on Impacts, costs and benefits of highly automated driving (day 2)

This multi-stakeholder workshop took place in Torino, Italy on 1-2 October 2019. The workshop put the focus on ODD, costs and benefits of highly automated driving. On Day 1 the workshop discussed the Operational Design Domains, their evolution path and the role they can play in type approval and certification (Proceedings from Day 1 can be accessed here). On Day 2 the workshop examined and discussed the costs and benefits of highly automated driving based upon existing research and projects.

The workshop welcomed everyone involved in shaping innovation in the automated driving. Overall, the Workshop attracted in all 37 participants with 15 from industry and the private sector, 17 from public sector and road operators, and 5 representing academia and research.

Day 2 October 2, 2019

Opening of the second day by Johnny Svedlund

1. Introduction to day 2: Goals, layout/agenda of workshop

Introduction to impacts, cost and benefits of highly automated vehicles: Magnus Hjälmdahl

Aim of the second day: Examine and discuss the costs and benefits of highly automated driving based upon existing research and projects.
Same groups as yesterday, building on the results. We start with introduction presentations. Plenty of time for the workshop and discussions.

Introduction of the Task 2 of EU EIP 4.2. Direct and indirect costs, road operator perspective but not only. Final Report due by the end of the year.

2. Impacts of highly automated vehicle – recent results

Presentation 1: Hendrik Weber: Impact Assessment in AdaptIVe and peek into L3Pilot

Hendrik Weber presented his research on AdaptiVe and in connection with L3Pilot. A safety impact assessment was conducted considering manoeuvre scenarios in which the

AVs must perform. The findings demonstrate how AVs in the given manoeuvre scenarios compare in terms of collision frequency relative to general collision data in Germany.

EuroFOT was a precursor and also did an impact assessment, next after that was Adaptive which ended two years ago. AdaptIVe did also an impact evaluation, and it will be done in the L3Pilot after the pilots.

AdaptIVe focused on Safety impact assessment (one use case) and Environmental impact assessment (all use cases)

Used accident data e.g. GIDAS database and building driving scenarios for the analysis. Using simulation which of course has some limitations. Environmental impact was assessed with the same methodology. Penetration rate is important but also usage data (if the functionality is actually used). Conclusion: Automation can have positive effect but that depends on penetration rate/usage.

Next is the L3Pilot where a lot of data will be collected and analysed – again safety and environment, followed by cost-benefit analysis.

Presentation 2: CARTRE, Scenarios and their benefits (Results of the CARTRE benefit evaluation based on the four future deployment scenarios): Pirkko Rämä VTT Principal Scientist

Pirkko Rämä presented the Impacts of automated driving CARTRE: Expert estimate in future deployment scenarios. A literature-based set of scenarios were applied to a small expert working group to evaluate the impacts to the success of shared mobility relative to the stress level on the role of public authorities. The findings demonstrate how the KPIs relate to targeted directions in categories (Use and Acceptance, Mobility and Travel Behaviour, Public Health and Safety, Land Use, Economic Benefits for the Society, Costs and Investments for Society). Relationship to ODD was also estimated.

CARTRE – Pirkko was leading the impact assessment part. Limited resources.
Ex-Ante: Long term effects by the decisions done now, socio-economic impacts cannot be estimated.

In CARTRE there were 17 experts. Eight impact areas were analysed. Initial KPI's coming from the tri-lateral EU-US-Japan cooperation in CAD. Complicated, so scenario-based approach using earlier work was adopted. The four scenarios were

1. Short term scenario
2. Shared mobility scenario
3. Authority driven and shared scenario
4. Private vehicles scenario

Results are opinions of the experts, not actual measured data:

CARTRE also estimated behavioural impact of highway autopilot and urban autopilot. Also, some preliminary estimates on network effects.

3. Workshop: Exploring and scoring benefits and costs

Explanation of the Excel tool by Vishal Baid, impacts value – 10 to +10 and weight from 0 to 100, for road operators and others – for different scenarios. Same for the costs, taken from previous work.

Parallel sessions per use case group, same as Day 1. The difference being in these sessions the participants worked with Impacts (Score and Weights for impacts), and costs (Score of costs for Road operators, Weight of costs for Road operators and Score for Others)

Use case group
Automated Passenger Cars
Automated Freight Vehicles
Urban Mobility Vehicles

a. Notes from Automated Passenger Cars (Highway Autopilot Level 4)

Detailed comments for Impacts and costs are mentioned below in the picture while some of the highlighted comments are:

- While weighting the impacts, five of the most significant impacts were chosen to give them relatively higher weight. These impacts were Traffic safety, Climate/Emissions/Biodiversity, Capacity (Road), Demand for/effort needed for road maintenance and Effort needed for traffic management.
- While weighting the costs for Road operators, two of the most significant costs were chosen to give them relatively higher weight. These costs were Cost of rebuilding existing

infrastructure and Maintenance cost for physical infrastructure with Cost for security getting a high weight as well.

- Costs like security and investment cost for digital infrastructure was discussed to be shared between the road authority and OEM/Tech or service provider.
- From the weighted scores for impacts, Capacity (Road) was found to be most significant with a negative impact while Traffic safety was found to be most significant with a positive impact.
- For the weighted score of costs for Road operators, it was seen that Costs for Security corresponds for most significant costs with increased/new costs. On the other hand, costs of accidents were found to decrease given the handling of accidents time and insurance process for Highway Autopilot (Level 4).

Use case: Highway Autopilot (Level 4)					
Impacts	-10	+10	Score	Weight* (Total=100)	Comment/justification
Congestion	Worsened a lot	Much improved	-3	12	More traffic demand, less accidents, increase headway even with v2v, smoother traffic? Not in mixed
Traffic safety	Worsened a lot	Much improved	4	25	ADAS, active safety already there? Still mixed traffic Avs to have lower speeds, if AV lowers safety they will be banned
Social equality	Worsened a lot	Much improved	-2	1	Cars more expensive/safety only for rich?
Capacity	Reduced a lot	Increased a lot	-6	12	Especially with dedicated lane
Demand for/effort needed for road maintanance	(a lot) Reduced possibilliteis	Much improved possibillities	-4	10	Keep ODD well enough/more traffic = more maintainance, Road operators willing to spend more? Regular/winter maintainace
Effort needed for traffic management	(a lot) Reduced possibilliteis	Much improved possibillities	-3	10	But possibilities increases if you get more data
Smother traffic flow (Less acceleration/deceleration)	Worsened a lot	Much improved	5	1	ACC studies TU Delft
Climate/Emissions/Biodiversity	Worsened a lot	Much improved	-2	14	More demand
Noise	Worsened a lot	Much improved	-1	4	More demand/more smooth/electric or not
Health (Active travel)	Worsened a lot	Much improved	-4	1	Car more attractive
Reliability & simplicity	Worsened a lot	Much improved	10	1	Driving tasks easier
Mobility/affordable mobility	Less affordable	More affordable	-1	1	Cost of car increases
Mobility for all (elderly, people with disabilities etc.)	Worsened a lot	Much improved	0.5	1	Still need driver, more rest time possible, confidence in new technology low
Space for parking	More space needed	Less space needed	-3	1	Demand increases
Public transport	Worsened conditions for PT	Improved conditions for PT	-3	1	Personal traffic will be more attractiv + congestion/capacity problems
Employment for society as a whole	Worsened a lot	Much improved	0	1	
Efficiency (Fuel/Electric)	lower	higher	6	1	Because of better flow (smoother)/slower speeds
Security	lower	higher	-5	3	
			Total	100	

Figure 16: Impacts for Highway autopilot (Level 4)

Use case: Highway Autopilot (Level 4)						
Costs	-10	+10	Score for Road Operators	Weight of cost* for Road Operators (=100)	Score for Others	Comment (i.e. is cost shifted between stakeholders?)
Costs for enforcement	Reduced a lot	Increased a lot	-1	2	3	Depends per country who is responsible, easier with AD/ODD enforcement needed or role for OEM/TMC
Costs for security			10	13	10	Roadside units V2I, V2V, National access point
Costs for new production of infrastructure			1	7	1	Gantries for rsas
Costs for rebuilding existing infrastructure			3	25	1	
Investment costs for digital infrastructure			5	10	5	HD map for eg. Extra communication needed? (5G)
Maintanance cost for physical infrastructure			2.5	25	1	Winter maintainance included? (base stations included)
Maintanance costs for legacy systems			0	1	0	For traditional cars still needed
Maintanance costs for digital infrastructure			2	10	5	
Costs of accidents			-4	7	-4	Handling of accidents of which here are less/ Insurance/Time?
			Total	100		

Figure 17: Costs for Highway autopilot (Level 4)

Use case: Highway Autopilot (Level 4)			
Impacts	Weighted score	Costs	Weighted score Road Operators
Congestion	-36	Costs for enforcement	-2
Traffic safety	100	Costs for security	130
Social equality	-2	Costs for new production of infrastructure	7
Capacity	72	Costs for rebuilding existing infrastructure	75
Demand for/effort needed for road maintanance	-40	Investment costs for digital infrastructure	50
Effort needed for traffic management	-30	Maintanance cost for physical infrastructure	62.5
Smother traffic flow (Less	5	Maintanance costs for legacy systems	0
Climate/Emissions/Biodiversity	-28	Maintanance costs for digital infrastructure	20
Noise	-4	Costs of accidents	-28
Health (Active travel)	-4		
Reliability & simplicity	10		
Mobility/affordable mobility	-1		
Mobility for all (elderly, people with disabilities etc.)	0.5		
Space for parking	-3		
Public transport	-3		
Employment for society as a whole	0		
Efficiency (Fuel/Electric)	6		
Security	-15		

Figure 18: Weighted scores for impacts and costs for Highway autopilot (Level 4)

b. Notes from Automated Freight Vehicles (Freight Hub to Hub)

Detailed comments for Impacts and costs are mentioned below in the picture while some of the highlighted comments are:

- Upon discussion it was realised that there were huge differences between countries and road operators, figures shown represent numbers for Sweden.
- While weighting the impacts, Congestion, traffic safety, climate/emissions/biodiversity were given the highest weight being more significant to road operators. Road/highway volume, Cyber security and construction were added to the list of impacts.
- Mobility of goods with the presence of automated freight vehicles will make roads more attractive which will then make them compete with railway and other modes.
- Cyber security which is not an issue today will be of importance in the future.
- Discussion were held about new service providers such as amazon and their status. What is the future of trucking? There will be some governance since the driver is not there. But who will take that cost, were some questions raised?
- Cost of security (cyber) was discussed to get higher, but it is unclear who will bear the costs.

Use case: Automated Freight Vehicles					
Impacts	-10	+10	Score	Weight* (Total=100)	Comment/justification
Congestion	Worsened a lot	Much improved	-1	20	What about following distance? Legal headway, legal weight. No drivers – lower costs – more traffic. Lower speeds would also lead to more congestion.
Traffic safety	Worsened a lot	Much improved	8	20	We anticipate mitigating measures in infrastructure and other traffic to accommodate for these vehicles, then the high score can be reached. Tough one, a lot of ifs and buts.
Social equality	Worsened a lot	Much improved	0	5	Could be an issue for low educated workers. In general not an issue for RO
Capacity	Reduced a lot	Increased a lot	-3	5	focus on peak capacity since that´s where the problem is. Assuming that speeds are lower we see a negative impact, if speeds and headway are more or less unchanged capacity is unchanged (lot of close following)
Possibillities for road maintanance	(a lot) Reduced possibilliteis	Much improved possibillities	-7		Maintenance and road works are outside the ODD which is worsening the situation. Possibly more traffic at night as well when a lot of maintenance is carried out. On the plus side the vehicles are safer and will not crash.
Possibillities for traffic management	(a lot) Reduced possibilliteis	Much improved possibillities	0		Tough, we put this to zero for now.
Smother traffic flow	Worsened a lot	Much improved	0	5	
Climate/Emissions/Biodiversity	Worsened a lot	Much improved	6	20	Microlevel on the vehicle it might be improved but macro it is worsened due to more traffic and reduced capacity. We see improvement and then add volume later.
Noise	Worsened a lot	Much improved	1		Might be lover, more traffic at night when noise is a bigger problem.
Health (Active travel)	Worsened a lot	Much improved	0		
Reliability & simplicity	Worsened a lot	Much improved	0		
Mobility/affordable mobility	Less affordable	More affordable			
Mobility for all (elderly, people with disabilities etc.)	Worsened a lot	Much improved			
Space for parking	More space needed	Less space needed	1		Slightly less. Vehicles will be parked at hubs and in between they will drive
Public transport	Worsened conditions for PT	Improved conditions for PT			
Employment for society as a whole	Worsened a lot	Much improved	-2		Truck drivers are not needed
Volume	Lower	Higher	5		We added volume as an impact. More traffic at off peak, more efficient transports
(Cyber) security	Increased risk of negative impact		-8		Not an issue today but will be, thus the high number (relative change).
Road service			-5	10	Rotting/tracks would be an issue. This has to be dealt with in designing the system. OEM:s has to prove that their vehicles does not worsening the situation.
Construction			-5	10	

Figure 19: Impacts for automated freight vehicles (Level 4)

c. Urban Mobility Vehicles:

The group on Urban Mobility vehicles had from 4 to 7 participants. The group decided to focus on two specific use cases: Automated shuttles on dedicated lanes and Robot taxis in mixed traffic. These two cases were regarded as provided interesting differences for analysis.

The group found the cost items to miss important elements and the following ones were added to the list:

- capital costs for fleet management centres
- operations cost for fleet management centres
- operations costs for traffic management centres
- costs for AV systems in vehicles
- personnel for fleet operations

Impacts

The group decided to colour the impacts, which are interrelated. Traffic safety and climate-related impacts were given the highest weights.

Impacts	-10	+10	Score	Weight* (Total=100)
Congestion	Worsened a lot	Much improved	-2	7
Traffic safety	Worsened a lot	Much improved	0	20
Social equality	Worsened a lot	Much improved	2	3
Capacity	Reduced a lot	Increased a lot	-4	6
Possibillities for road maintanance	(a lot) Reduced possibilliteis	Much improved possibillities	-5	9
Possibillities for traffic management	(a lot) Reduced possibilliteis	Much improved possibillities	-5	9
Smoother traffic flow	Worsened a lot	Much improved	-2	7
Climate/Emissions/Biodiversity	Worsened a lot	Much improved	-1	18
Noise	Worsened a lot	Much improved	1	2
Health (Active travel)	Worsened a lot	Much improved	1	5
Reliability & simplicity	Worsened a lot	Much improved	1	3
Mobility/affordable mobility	Less affordable	More affordable	1	3
Mobility for all (elderly, people with disabilities etc.)	Worsened a lot	Much improved	1	3
Space for parking	More space needed	Less space needed	1	2
Public transport	Worsened conditions for PT	Improved conditions for PT	3	3
Employment for society as a whole	Worsened a lot	Much improved	-1	0

Figure 20: Impacts for automated PRT shuttles in dedicated lanes (Level 4)

Impacts	-10	+10	Score	Weight* (Total=100)
Congestion	Worsened a lot	Much improved	-5	7
Traffic safety	Worsened a lot	Much improved	4	20
Social equality	Worsened a lot	Much improved	5	3
Capacity	Reduced a lot	Increased a lot	-4	6
Possibillities for road maintanance	(a lot) Reduced possibilliteis	Much improved possibillities	-5	9
Possibillities for traffic management	(a lot) Reduced possibilliteis	Much improved possibillities	1	9
Smoother traffic flow	Worsened a lot	Much improved	2	7
Climate/Emissions/Biodiversity	Worsened a lot	Much improved	-1	18
Noise	Worsened a lot	Much improved	1	2
Health (Active travel)	Worsened a lot	Much improved	-3	5
Reliability & simplicity	Worsened a lot	Much improved	7	3
Mobility/affordable mobility	Less affordable	More affordable	4	3
Mobility for all (elderly, people with disabilities etc.)	Worsened a lot	Much improved	4	3
Space for parking	More space needed	Less space needed	5	2
Public transport	Worsened conditions for PT	Improved conditions for PT	-3	3
Employment for society as a whole	Worsened a lot	Much improved	-2	0
			Total	100

Figure 21: Impacts for robo taxis in mixed traffic (Level 4)

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Costs

For costs, the group decided to give highest weights to the cost items, which play the largest roles in the road operator budgets. the selected high weight cost items were:

- Costs for new production of infrastructure
- Costs for rebuilding existing infrastructure
- Investment costs for digital infrastructure
- Maintenance cost for physical infrastructure
- Maintenance costs for legacy systems
- Maintenance costs for digital infrastructure
- Operations costs for traffic management centers

Use case: Shutles in Dedicated Lanes						
Costs	-10	+10	Score for Road Operators	Weight of cost* for Road Operators (=100)	Score for Others	Comment (i.e. is cost shifted between stakeholders?)
Costs for enforcement	Reduced a lot	Increased a lot	0	2	4	Increased enforcement requirements by police
Costs for security			3	4	2	concerns (e.g. pysical threats or unattended baggage) in un-manned vehicles
Costs for new production of infrastructure			4	15		Depends on whether the dedicated lanes are new construction or use of exisitng dedicated lanes
Costs for rebuilding existing infrastructure			6	15		
Investment costs for digital infrastructure			8	10	6	Private operators will also need to develop some digital infrastructure
Maintanance cost for physical infrastructure			4	15		Roadway operators are anticipating that OEMs will fulfill their oroginal predictions that the sensor technology will eliminate
Maintanance costs for legacy systems			-2	10		
Maintanance costs for digital infrastructure			6	11	8	Private operators will also need to maintain some digital infrastructure
Capital Costs for Fleet Management Centers			4	4	4	maintenance fleet activities are often managed by the road operators
Operations Cost for Fleet Management Centers			4	4	4	maintenance fleet activities are often managed by the road operators
Operations Costs for Traffic Management Centers			2	10		
Costs for AV systems in vehcles			0	0	8	Cost for AV systems are born by the fleet operators
Personnel for fleet operations			-1	0	-10	One primary argument for AVs is that they will reduce the personnel costs of the fleet, but this savings is born by the flet operaator, rather than the road operator
			Total	100		

Figure 22: Costs for automated PRT shuttles in dedicated lanes (Level 4)

Use case: Robotaxis in Mixed Traffic						
Costs	-10	+10	Score for Road Operators	Weight of cost* for Road Operators (=100)	Score for Others	Comment (i.e. is cost shifted between stakeholders?)
Costs for enforcement	Reduced a lot	Increased a lot	0	2	-4	reduced enforcement requirements by police
Costs for security			3	4	2	concerns (e.g. pysical threats or unattended baggage) in un-manned vehicles
Costs for new production of infrastructure			2	15		Pick-up/drop-off bays are required for robo-taxi operations in urban areas. Inclement weather parking areas are requried on highways
Costs for rebuilding existing infrastructure			3	15		
Investment costs for digital infrastructure			8	10	6	Private operators will also need to develop some digital infrastructure
Maintanance cost for physical infrastructure			4	15		Roadway operators are anticipating that OEMs will fulfill their oroginal predictions that the sensor technology will eliminate
Maintanance costs for legacy systems			-2	10		
Maintanance costs for digital infrastructure			6	11	8	Private operators will also need to maintain some digital infrastructure
Capital Costs for Fleet Management Centers			4	4	4	maintenance fleet activities are often managed by the road operators
Operations Cost for Fleet Management Centers			4	4	4	maintenance fleet activities are often managed by the road operators
Operations Costs for Traffic Management Centers			2	10		
Costs for AV systems in vehcles			0	0	5	Cost for AV systems are born by the fleet operators or car owners
Personnel for fleet operations			-1	0	-10	One primary argument for AVs is that they will reduce the personnel costs of the fleet, but this savings is born by the flet operaator, rather than the road operator
			Total	100		

Figure 23: Costs for robot taxis in mixed traffic (Level 4)

4. Feedback and discussion

Short presentations of the groups

Urban Mobility Vehicles: two use cases, shuttles on dedicated roads, robotaxis in mixed traffic. The costs for shuttles obviously depend if there is remote operation and no driver in the bus. Only four people in the group. Operational costs quite important.

Automated Freight Vehicles: discussed a lot on impacts, a lot of dependencies, use case is hub to hub freight. Only made this use case. Discussion if the vehicles travel at the same speed than other vehicles. Electric or not? Big discussions on weights. The discussion was more interesting than the result. Costs: Dedicated lanes would of course

increase cost. Discussion on the business models. A question is if road operators are competent to discuss this. In all 9 people.

Automated Passenger Cars: Biggest group 12 people. Discussion also more valuable than result. Good methodology. Combined some attributes to the weight. Had to have a lot of assumptions. Use case Highway Autopilot. The weight of the costs was difficult to estimate. Could be that if there is a high cost for road operators it should be avoided. Roadside Units: Are they digital or physical infrastructure.

9.3. Regulatory framework to promote truck platooning in EU

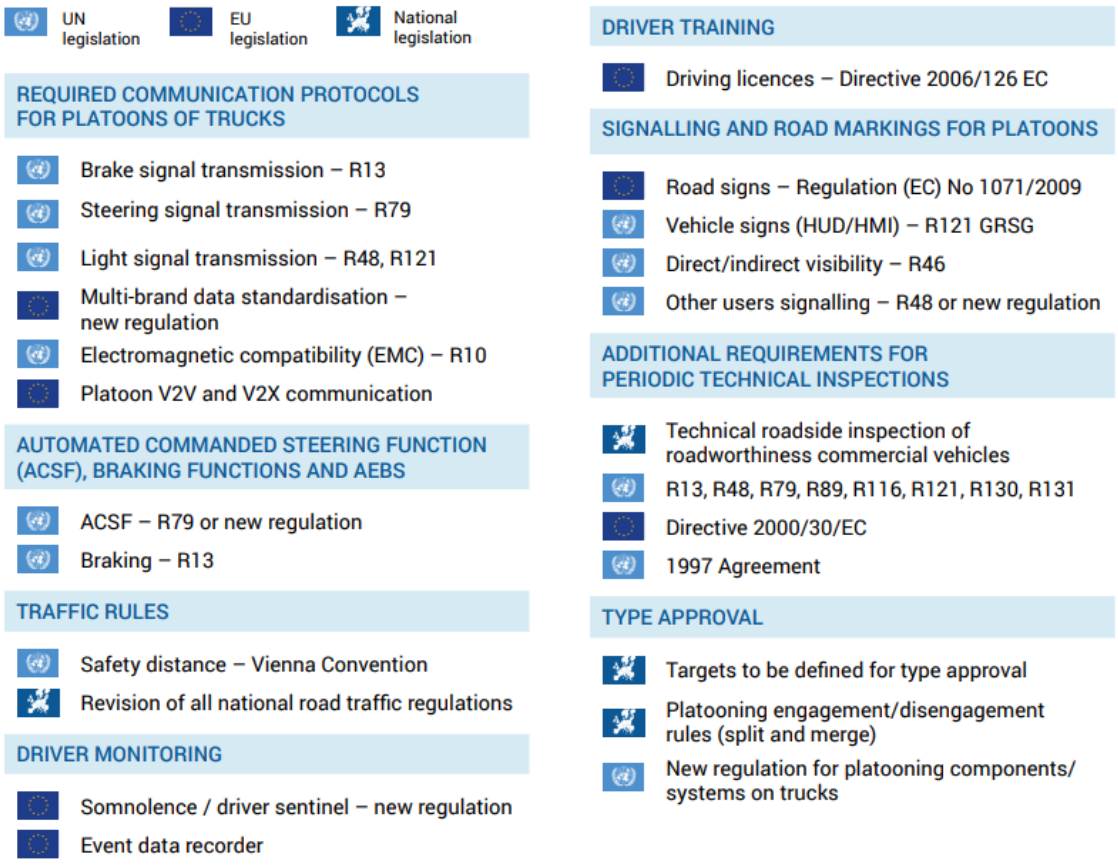

Figure 24: Regulatory framework to promote Truck platooning in EU

9.4. Table of Abbreviation

Abbreviation	Full form
ACC	Adaptive Cruise Control
AD	Automated Driving
ADAS	Advanced Driver - Assistance Systems
ADS	Automated Driving System
API	Application Programming Interface
AV	Automated Vehicle
AVP	Automated Valet Parking
C-ACC	Cooperative Adaptive Cruise Control
CAV	Connected Automated Vehicle
CCAM	Cooperative, Connected, Automated and Autonomous Mobility
C-ITS	Cooperative Intelligent Transport Systems
DDT	Dynamic Driving Task
GM	General Motors
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
HMI	Human Machine Interface
ICT	Information and Communications Technology
ISA Levels	Infrastructure Support for Automated Driving
ITS	Intelligent Transport Systems
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
MaaS	Mobility-as-a-Service
MCDCA	Multi Criterion Decision Analysis

ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OEM	Original Equipment Manufacturer
RTK	Real Time Kinematics
SAE	Society of Automotive Engineers
TEN-T	Trans-European Transport Network
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to X
VMS	Variable Message Sign
VRU	Vulnerable Road Users