

## JRC SCIENCE FOR POLICY REPORT

# The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART)

*Part I: Framework for a  
safe & efficient  
Coordinated Automated  
Road Transport (C-ART)  
system*

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#### The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART)

Connected and automated vehicles could revolutionise road transport. New traffic management approaches may become necessary, especially in light of a potential increase in travel demand. Coordinated Automated Road Transport (C-ART) is presented as a novel approach that stakeholders may consider for an eventual full realisation of a safe and efficient mobility system.

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## **Executive summary**

The future of driving will be radically different from what we know today, as a result of drastic changes that are expected with the introduction of automated and connected vehicles. Evolutionary and revolutionary scenarios may become real, with different socio-economic impacts. Some kind of central management may become necessary in order to guarantee that the full system benefits of road transport automation can be reaped. Coordinated automated and connected vehicles (*Coordinated Automated Road Transport, C-ART*) are investigated in this study as they could contribute to avoid possible negative consequences of road automation and enable a safe low emission mobility.

### ***Policy context***

This study suggests exploring C-ART as a new forward-looking approach for traffic flow and system management in the presence of highly automated and connected vehicles. A number of political and legislative aspects are currently being discussed in different international and European fora. These apply to existing legislative frameworks such as the 1968 Vienna Convention on international road traffic, Directive 2009/103/EC on motor insurance, or Directive 2007/46/EC on vehicle approval, among others, that may require modifications. This report analyses the current technological context, policy and legal framework for automated and connected vehicles. Besides, by examining future scenarios, it identifies areas that deserve special attention. This study presents a novel approach, based on a central coordination of fully automated and connected vehicles (i.e. C-ART), that policymakers and different stakeholders may want to consider as a scenario for an eventual full realisation of a safe and efficient mobility system.

### ***Key conclusions***

The findings of this study highlight the need for advanced demand management strategies like C-ART. Analysing further the implications of automated and connected vehicles on areas like inter alia technology, data, human factors, and ethics, the following main policy-relevant conclusions can be drawn:

- Since C-ART relies on highly automated driving technologies (mainly level 4 and level 5), legal actions need to be undertaken to ensure that they can be safely deployed in real driving conditions (including without any occupant).
- Similarly, V2X connectivity (mostly V2I) will be essential in C-ART as AVs need to communicate with the central management system.
- Road infrastructure requirements are indispensable in this context, mainly including communication equipment such as road side units to communicate with AVs and with the management system, and digital infrastructure (being data standardisation an aspect of major relevance).
- Since C-ART requires that automated vehicles' algorithms are known by the system, (at least up to a certain degree), data sharing becomes an essential pillar. This is linked to crucial aspects such as data privacy and data security.
- The use of both dedicated in-vehicle interfaces for C-ART relevant messages and external vehicle HMI to inform about vehicle's intentions to other road users are understood to be of relevance for an appropriate user experience with the C-ART system (thus contributing to users' acceptance and in the end adoption of the system).
- Proper care should be given in the definition of rules and criteria governing the C-ART real time decision making process.

Further work on these areas, as concerns the definition of framework requirements for a C-ART-like system, is necessary to clarify and extend the recommendations provided.

## **Main findings**

**Connected and automated vehicles promise** to reduce road accidents, traffic congestion, traffic pollution and energy use, as well as to increase productivity, comfort and accessibility. **However**, the road transport system is complex and the potential impacts of these technologies, which could contribute to totally reshape the vehicle use paradigm, are mostly uncertain and could even have undesirable consequences. The **increased road transport demand**, which is expected to arise with highly automated vehicles, may at some point exceed the available road capacity, thereby potentially leading to **congestion peaks**, with severe consequences. **The role of transport authorities in managing transport automation in real time can become crucial**. After public authorities' initial enabling efforts, a totally different role can be played, in order to ensure that the potential benefits of vehicle automation are actually delivered with automated vehicles integrated in the management of the whole transport system.

In particular, this study presents two main scenarios based on the expected socio-economic impacts of automated and connected vehicles in two timeframes:

- **C-ART 2030:** *AVs account for a small percentage of vehicle fleet and coexist with conventionally driven vehicles. Big safety risks remain. Road capacity is reduced in this scenario.* C-ART could provide partial benefits in such a scenario, as it will first be implemented in parts of the whole road transport network. For vehicles travelling through the C-ART network, reductions in accidents, congestion, fuel consumption, and emissions would be expected.
- **C-ART 2050:** *AVs represent a substantial portion of road transport, almost achieving a 100% penetration rate. Road transport demand increases significantly in this scenario. Road capacity is also increased but, at times, may not off-set the effect of increased demand in certain points of the network.* Full system benefits can only be guaranteed when C-ART controls the whole road transport network. As consequence, AVs would smoothly travel, minimising the environmental impact while providing very high safety and comfort levels to end users.

These scenarios highlight the potential need and benefits of implementing a central coordination system and serve as a basis for a preliminary conceptual definition of the C-ART system. A number of C-ART framework requirements are elaborated in the report, identifying where EU action could be of special relevance. Technology, policy, and users are three main pillars to be taken into consideration in the transition to fully automated and connected vehicles, eventually enabling C-ART.

## **Related and future JRC work**

The work for this study has been performed in the frame of an exploratory project. Ongoing work of the JRC on sustainable transport, emissions modelling, security of connected vehicles as well as on big data are key enablers in this context. Immediate next steps will concern the continuation of present research on the feasibility of a central road transport management system for automated and connected vehicles: from a modelling and simulation perspective as well as from the users' and stakeholders' perspective.

## **Quick guide**

Connected vehicles (i.e. vehicles that can communicate with other vehicles and with the infrastructure) and automated vehicles (i.e. vehicles that can drive without human input, with varying degrees) are forthcoming and will transform the way in which we presently move. Main long-term implications are the potential increase in road transport demand (latent and induced) and road capacity. A mismatch between both may occur. Coordinated automated road transport could ensure maximum system benefits. This study has been informed by comprehensive desk research and will be used as input for discussions with key stakeholders (through a dedicated workshop on 12-13 June 2017, whose outcomes will be featured in a follow-up report on the stakeholder views, to be delivered by the end of 2017).

# 1 Introduction

In the next 30 years, the transport sector will undergo a deep transformation with the advent of automated and connected vehicles. The already existing connectivity will in the short term give way to cooperative features that will enable vehicles to interact with each other and with the surrounding infrastructure (i.e. Vehicle-to-Vehicle V2V and Vehicle-to-Infrastructure V2I communication). Full scale deployment of Cooperative Intelligent Transport Systems (C-ITS) enabled vehicles, i.e. vehicles that warn other vehicles of potentially dangerous situations and communicate with local road infrastructure, will start as early as in 2019 (CAR 2 CAR Communication Consortium, 2015). Additionally, vehicle automation is already being experienced in manifold applications. Automotive manufacturers and technology companies like BMW, Ford, Toyota, Volvo, Google or Tesla, have set 2020 as a target date for the market launch of vehicles with high automated features (Muoio, 2016). Future projections estimate that by 2025 high automation driving will be available in highways and by 2030 in cities (Dokic et al., 2015). Last, the year 2050 is described as a futuristic scenario with innovative visions of tomorrow's mobility (Sessa et al., 2013). With these outstanding milestones in the short, medium and long terms, a forward-thinking approach becomes necessary in order to anticipate possible obstacles and make the most of automated and cooperative technologies by leveraging its full socio-economic and environmental improvement potential.

Automated and connected vehicles promise to substantially reduce road accidents, traffic congestion, traffic pollution and energy use. They also promise to increase productivity and comfort and to facilitate a greater inclusion in mobility of specific groups of individuals such as disabled or elderly. However, some of these potential benefits are uncertain to a great degree. The road transport system is a complex one where road users, vehicles and infrastructure interact with each other and millions of decentralized decisions are taken by human drivers every second. Automated and connected vehicles would certainly contribute to reduce road accidents by eliminating human errors, which are a contributing factor in a vast majority of road accidents. At the same time, most of the accidents occur due to risks that human drivers continuously take consciously and unconsciously due to the experience gained in more than one hundred years of driving activities. If on the one hand these risks generate road accidents with all their negative consequences, on the other hand these risks have a positive effect on the capacity of the road transport system. The introduction of automated vehicles, which by definition will be designed to minimize the risk of accidents, could therefore have a negative effect on road capacity especially in a transition period where a mix of conventional and automated vehicles will be sharing the same infrastructure. In addition, the increased travel demand on roads which could arise with automated and connected vehicles may further worsen the situation and their introduction may actually lead to higher congestion levels. Increasing congestion would then bring about severe consequences on the environment as well as on the mobility of people and goods. In this context, the present study aims at analysing the impacts of automated and connected vehicles, exploring plausible scenarios where a coordination of the whole road transport system would enable the full potential of these technologies to be deployed.

Future projections estimate a gradual increase in vehicle's autonomy features, thereby representing an evolution of currently available driving assistance technologies. However, in the long term, automation could have a revolutionary impact on travel behaviour and urban development. This latter scenario is where the concept of Coordinated Automated Road Transport (C-ART) presented in this study stands. C-ART is an extension of the automated driving paradigm, in which vehicles are not only able to move without human intervention (automated), but are also coordinated in order to maximize the overall efficiency of the transport system (connected and coordinated). Vehicle's connectivity will be the first element, automation will follow and it will represent the final enabler for the management of the entire transport system.

A unique and simple solution will hardly exist. For this reason, it is crucial to foster discussions and debate on these topics. Plenty of attention is being given worldwide to automated and connected driving. Specifically in the European Union, the past decade has



shown significant progress with the development of Advanced Driver Assistance Systems (ADAS, such as e.g. Forward Collision Warning) and C-ITS (like e.g. weather conditions warning). Recently, the following initiatives have taken place in the EU and internationally: the G7 declaration on Automated and Connected driving (European Commission, 2015d), the Round Table on Connected and Automated Driving (European Commission, 2015c), the Gear 2030 initiative (European Commission, 2016c) and the Declaration of Amsterdam (European Union, 2016). Altogether, these combined efforts underline the relevance of adopting a harmonised and coherent European regulatory framework, enabling a safe deployment of these technologies across national borders. The increased level of connectivity and autonomy of road vehicles will most probably lead in the future to a complete transformation of road transport. From the political perspective, there is the desire that this transformation makes road transport more efficient in economic, environmental and social terms. Researchers in the traffic community are therefore called to provide tools able to support the transformation and to assess new possible scenarios. Besides, as the elements of the transport system become increasingly interconnected, it is necessary to adopt a holistic approach in which the complex interactions among different players such as vehicles, drivers, infrastructures, policies, citizens, energy, economy and environment are explicitly taken into account. Embracing a full perspective will allow to analyse potential future configurations and include all the actors who are part of this profound change. In addition, ambitious targets for safety and environmental improvements require an ambitious forward-looking approach. In this framework, this JRC study is adopting a holistic and forward-looking perspective to address the stated challenges. Along the report the terms Automated Vehicle (AV) and Automated Road Transport (ART) have been adopted, in line with what SAE J3016 recommends (SAE International, 2016) and the European scientific community is using.

## **1.1 Purpose of the study**

New developments in automated driving raise concerns regarding personal safety, privacy, cyber-security, liability, user benefits and environmental benefits. There are underlying questions that need to be addressed. For instance: Who will take the liability in case of an accident? How will AVs deal with a malfunctioning of the vehicle? Will traffic congestion and emissions be reduced? Which data are required by the AVs for a fast, safe, reliable and efficient mobility? How will the huge amount of generated data be managed? Would it be feasible to connect AVs to a central controller and how should it operate? What is the users' perception of AVs? Which ethical judgements are involved in AVs and C-ART? Which new business models may appear? What can we learn from other sectors where autonomous systems exist (e.g. aviation)? The authors are trying to address some of these questions, with the aim of helping industry players, researchers and policymakers understand the implications of automated and connected vehicles, driving future developments in this rapidly emerging technology area.

In order to explore the feasibility of C-ART, the following specific concerns emerge:

- Which data are required by the AVs for a fast, safe, reliable and efficient mobility? (Devices needed? Synergies with enabling technologies like 5G or Galileo? Data requirements? Which data to be provided and maintained by road transport authorities? Which types of data will need management? Do we need to store all data? Data privacy concerns? Security concerns?)
- How to manage huge amounts of data? (Transmission problems? Latency issues? Do we consider the same order of volumes for individual AV management as for C-ART management or are these two different approaches? Which data can be shared?)
- AVs connected to a central controller? How should it optimize the transport system? (Who should govern it? Prioritization / Optimization criteria? E.g. travel time, costs, energy use, air pollution, accident risk, etc. At which level? E.g. urban, rural, national. Which are related challenges, also computationally?)

- Would AVs need to undergo an examination to obtain a driving license or can this be covered through the type approval procedure? (Testing?)
- Operational issues? (e.g. roadway types, geographical location, speed, range, lighting conditions (day and/or night), weather conditions, cross-border driving...?)
- What is the view of the industry? Is AV coordination feasible with the existing technologies? What kind of technologies are proposed?
- How to manage a mix of AVs and conventional vehicles? (Problems arising from their interaction? Is retrofitting of old vehicles possible?)
- Should drivers have the right and freedom to overrule the controller's decisions? (Always, on certain time periods or in specific areas?)
- What is the users' perception of AVs? (Trust? Losing joy of driving? Willingness to buy one? Willingness to pay for services? Safety, efficiency and environmental impact influencing their choice? Interaction with pedestrians?)
- Which new business models may appear? (New mobility services?)
- Need for consumer education and training?
- Who is liable for an accident? (Car manufacturer or Driver/Car owner or the Infrastructure/authority? Who is responsible for the central controller in the case of C-ART?)
- Ethical judgements? (Not only in terms of AV decision but also AV coordination)
- Standardization of AVs?
- Which is the current status of policies and legislation on AVs? (Policy implications? Applying laws at different levels?)
- What can we learn from other sectors where automated systems exist? (Aviation)

This study aims at shedding light on these open questions by gathering key literature contributions and views from main stakeholders (e.g.: automotive companies, technology companies, telecommunication companies, transport networking and car sharing companies, insurance companies, road authorities, city authorities, research centres, universities, associations). It aims to help industry players, researchers and policymakers understand the implications of automated and connected vehicles, driving future developments in a rapidly emerging technology area.

Precisely, the present study has been undertaken to address the following objectives:

- Analyse the state-of-the-art of the development and deployment of automated and connected vehicles and solutions being proposed for their management.
- Address existing barriers and needs at conceptual, legislative and technological levels.
- Explore synergies with electro-mobility and different enabling technologies.
- Explore the long-term feasibility of C-ART, identifying its benefits and challenges and devising potential future pathways.

## **1.2 Scope: EU policy/legislation addressed in this study**

Transport is fundamental to our economy and society and, as stated in the roadmap to a Single European Transport Area, *"it is essential to understand how to better respond to the desire of citizens to travel and the needs of economy to transport goods, while at the same time anticipating resource and environmental constraints"* (European Commission, 2011). Air pollution is estimated to cause almost 500,000 premature deaths a year in Europe (European Environment Agency, 2016). Transport is the only major sector in the EU where Greenhouse Gas (GHG) emissions are still rising and it is a major cause of pollution in cities. In particular, road transport accounts for more than 70% of all transport GHG emissions. It represents one quarter of the EU's overall energy consumption, with one fifth

of the EU's CO<sub>2</sub> emissions caused by road vehicles. World GHG emissions need to be drastically reduced for limiting climate change to 2°C. In order to reach this goal, the EU needs to reduce emissions by 80-95% below 1990 levels by 2050. Applied to the transport sector, a reduction of at least 60% of GHGs with respect to 1990 by 2050 is required. The Energy Union Package (European Commission, 2015b) establishes one priority area related to more sustainable transport systems that develop and deploy at large scale innovative technologies and services to increase energy efficiency and reduce GHG emissions. The Commission Strategy for Low-Emission Mobility (European Commission, 2016b) identifies the need for increasing the efficiency of the transport system by making the most of digital technologies, especially through C-ITS and successively, automated vehicles. Furthermore, road safety is a major societal concern. In 2015, more than 26,000 people died and nearly 1.5 million people were injured on the roads of the European Union (European Commission, 2016d). Worldwide, there were 1.25 million of road traffic deaths in 2013 (WHO, 2015). As stated in the 10 goals for a competitive and resource efficient transport system (European Commission, 2011), the EU aims to move close to zero fatalities by 2050. An intermediate target is set to halve road casualties by 2020 with regard to 2010 figures. To achieve these goals, it is important to acknowledge that human error has been identified as a contributing factor in over 90% of all road accidents (Smith, 2013). Therefore, reducing or eliminating human errors with the support of automated and connected technologies would be an effective way of tackling the road safety problem. Although distinct, automated and connected vehicles are linked together as they can jointly enable the full potential of driverless technology (European Commission, 2016a). In this context, automated and connected vehicles hold considerable promise in facing the challenges and reaching the ambitious long term targets.

The increasing amount of data which is generated, collected, processed and shared in our daily mobility holds enormous potential for the optimization of the transport system. The availability of this information in real time could considerably improve transport efficiency, sustainability, safety, mobility and comfort. Exchanging data between different actors in the transport system means supply and demand can be matched in real time, leading to a more efficient use of resources (European Commission, 2016a). *"Intelligent Transport Systems (ITS) are advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks"* (European Union, 2010). *"Applied effectively, ITS can save lives, time and money as well as reduce the impact of mobility on the environment."* (Nowacki, 2011). As part of the Digital Single Market Strategy (European Commission, 2015a), the European Commission aims to make more use of ITS solutions to achieve a more efficient management of the transport network for passengers and business. The C-ITS communication from November 2016 (European Commission, 2016a) highlights the relevance of cooperative, connected and automated vehicles for boosting the competitiveness of European industry, with a market potential worth dozens of billions of euro annually and hundreds of thousands new jobs created and for reducing energy consumption and emissions from transport.

The development and deployment of automated and connected driving technologies should be supported by coherent transport research and innovation policies as well as appropriate regulatory framework conditions. Given the broad dimension of C-ART, there are diverse issues that necessitate guidance and/or legislation. The main existing EU legal and policy frameworks in relation to automated and connected driving are listed below:

- 1949 Geneva Convention on Road Traffic
- 1968 Vienna Convention on international road traffic
- Directive 2006/126/EC on driving license
- Directive 2003/59/EC on training and initial qualifications of professional drivers
- Directive 2009/103/EC on motor insurance

- Directive 85/374/EEC on product liability
- Directive 2007/46/EC on vehicle approval
- Directive 2014/45/EU on roadworthiness
- ITS Directive 2010/40/EU
- Directive 95/46/EC on data protection
- Directive 2002/58/EC on privacy in electronic communications
- Directive 2008/96/EC on infrastructure safety management
- UN Regulation No. 116 on anti-theft devices
- UN Regulation No. 79 for steering equipment
- UN Regulation No. 131 laying down the technical requirements for the approval of Advanced Emergency Braking Systems (AEBS) fitted on trucks and coaches
- Declaration of Amsterdam
- C-ITS communication

In addition, there are different national rules and legislation at EU Member States Level, such as: traffic rules, rules on motor insurance and product liability, legislation for roadworthiness and maintenance, laws on ITS, data protection, privacy, infrastructure requirements.

The mentioned legislation may need to be modified to accommodate for the new conditions imposed by automated and connected vehicles, and new regulation and/or standards may become necessary. This study reviews the current legal and policy framework and outlines the need for further actions in this area.

### **1.3 Work methodology and organisation of the report**

This study has been informed by comprehensive desk research and discussions with key stakeholders. Evidence is presented in accordance to up-to-date research outcomes and published materials in different areas inter alia technology, legislation, policy. Likewise, stakeholders and policy makers have been consulted through a dedicated workshop on the challenges and opportunities of C-ART. By doing this, a holistic approach to C-ART has been adopted, ensuring that different perspectives are considered in the quest for an optimised automated road transport system. The study has been divided in two reports:

- The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART). Part I: Framework for a safe & efficient Coordinated Automated Road Transport (C-ART) system.
- The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART). Part II: Stakeholders Workshop and Surveys with experts.

The present report covers Part I and will be used as an input for the stakeholders workshop on the challenges and opportunities of C-ART which will be held on 12-13 June 2017. The results of the workshop together with the outcomes of the experts surveys will be integrated in Part II of the report and will be delivered separately at the end of 2017.

The remainder of the report is structured as follows:

- Chapter 2 describes the C-ART vision as a result of the shift from connected vehicles to the long-term future situation where road transport would rely on connected and coordinated fully automated solutions.
- Chapter 3 defines a framework for C-ART, providing answers to the open questions on the basis of literature and informal stakeholders' feedback (obtained prior to the workshop).

- Chapter 4 presents future pathways of vehicle connectivity and autonomy technologies in the short term, medium term and future term under different perspectives. It also identifies where EU action may be needed.
- Last, Chapter 5 draws final conclusions.

## 2 From Connected Vehicles to the C-ART system

This chapter describes the C-ART vision as a result of the shift from AVs to the long-term future situation where road transport would rely on connected and coordinated fully automated solutions. It provides a rationale on the basis of potential impacts of AVs in different timeframes, reviews studies and systems similar to C-ART, outlines the resulting C-ART scenarios and frames the initial concept of C-ART.

### 2.1 A vision of the future: the C-ART system

*"The future of driving will be radically different from what we know today, as a result of drastic changes that are expected to take place in the transport system along the oncoming decades. As a driver (or we should better say as a passenger) in the future, you will travel in fully automated vehicles which are connected to the network and coordinated for an optimisation of travel times, travel costs, energy consumption, air pollution and collision risk. Your car will be guided throughout the entire journey, following the roads network capacity restrictions. You will be informed of your assigned road access time slot and estimated journey travel time, fuel/energy consumption, emitted pollutants and other journey related details. During your journey you will be able to use the car as a 3<sup>rd</sup> space: You will be able to work, read a book or take a nap while on the drive. You will have access to internet-based services and stay connected during the move. Once you reach your destination, your automated car (or possibly a shared automated car that you use as a service) will be automatically guided to the parking spaces and will stay parked there until a new request is made. You will get a message with actual journey specifics at the end of your car trip. You will seamlessly combine modes of transport in order to better satisfy your mobility needs, i.e. on demand multimodal transport. You will be able to travel where you want independently of your age or physical condition. In a new redesigned urban space, you will be able to walk and cycle in the safest possible conditions. Also, an efficient automatic delivery of items to you even while on the move will be likely with automated transport solutions. The borders between virtual and physical connectivity will vanish. This future driving concept is enabled by a coordinated automated road transport system."*

*A vision of Coordinated Automated Road Transport (C-ART), 2050*

This vision reflects a threefold shift. First of all, a shift from conventional vehicles to connected vehicles. Secondly, from connected vehicles to automated vehicles. And eventually, a shift from automated vehicles to a Coordinated Automated Road Transport (C-ART). C-ART is meant as an extension of the automated driving concept by adding communication capabilities that connect vehicles in between and with the infrastructure and adding a central coordination player to achieve the full potential of automated driving in terms of social, economic and environmental benefits. Connectivity and central coordination would expand the automation capabilities to what has been referred to as C-ART. C-ART is founded on highly automated and connected vehicles and connected infrastructure and represents a long distant scenario.

The rationale behind C-ART is that AVs by themselves will not necessarily be smarter than conventional vehicles driven by humans (Ciuffo et al., 2016). AVs will follow more rational rules, but without coordination they will try to find their individual optimal solution only in a more analytical way. The existing interaction loop between traffic information and traffic conditions will certainly remain. The existing heterogeneity of vehicle behaviour, which is considered one of the main causes of traffic instability (Ngoduy, 2013a; Ngoduy, 2013b), is not expected to be reduced, as vehicle technologies will continue to be very differentiated and each vehicle manufacturer will implement (and keep strictly confidential) its own driving logic. In theory, the reaction time of an automated vehicle can be significantly smaller than that of a normal driver leading to a significant increase in road capacity (Kesting and Treiber, 2008). However, liability issues on the responsibility of automated vehicles would force vehicle manufacturers to design their vehicles to be fairly conservative, a serious problem when mixed vehicles (automated and conventional) will be on the roads. Additionally, contrary to what is anticipated, traffic conditions may even get deteriorated as they are closely related to the traffic demand which in turn will increase, as potentially additional demand will arise from new user groups (elderly, children, etc.),

currently having access barriers to individual motorised mobility. The rebound effect <sup>(1)</sup> will probably limit the capabilities of AVs to make the entire transport system more efficient. With significantly more vehicles on the road, any disruption, although potentially less frequent than in today's conditions, might lead to extreme situations and may expose citizens to very high risks <sup>(2)</sup>. In this scenario, as in other capacity-constrained system like railway or aviation, we highlight the need for central coordination and regulation regarding the access to the road system.

The role governments will decide to play will be very important. In an initial phase, public authorities are mainly acting as enablers, providing the framework in which industry and operators can deploy new technologies and systems and in which they can position themselves, while at the same time trying to avoid creating obstacles to them. At a certain point, however, in order to ensure that the potential benefits of vehicle automation are actually delivered, a totally different role can be played, with AVs integrated in the management of the whole transport system. This new role may imply, for instance, deciding to move from a 'car-ownership' model to a 'car as a service' one and from free driving to full control of AVs for a system optimization. Adding intelligence to the whole transport system by means of a central coordination actor is an alternative that could contribute to the complete fulfillment of the potential benefits associated with automation. As in other capacity-constrained system (e.g. aviation, railway), we highlight the need for central coordination and regulation regarding the access and use of the road transport system.

In the road to the realisation of automated driving and ultimately C-ART, there are two approaches: "Something everywhere" versus "Everything somewhere". The "Something everywhere" approach is generally embraced by traditional car manufacturers which offer AVs with varying levels of automation and increasingly sophisticated ADAS. It involves initially having lower levels of automation but covering different road environments and situations. This approach is likely preferred by wealthy consumers and fleet operators. On the contrary, the "Everything somewhere" approach is primarily focusing on urban areas and refers to a high level of automation in dedicated spaces. It is usually embraced by disruptive players (e.g. technology companies). The latter represents systems that are close to the market, given that in case any irregularity occurs, the system might enter in a minimal risk mode simply by stopping the vehicle and requesting assistance (Smith, 2014). These systems hold promise for both passenger and freight applications. Automated passenger shuttles <sup>(3)</sup> could be particularly well suited for airports, city centres, business clusters, university campuses, convention centres, military bases, retirement communities, amusement parks, and last-mile transit applications. The "Everything somewhere" approach reaches a more diverse group of users, e.g. people unable to drive or who cannot afford to buy or maintain a private car. Respectively, each approach corresponds to the so called Evolutionary and Revolutionary approaches.

The impacts of automated and connected vehicles are still unknown and require further research in the coming years as automated and connected vehicles are deployed. Nevertheless, some preliminary assumptions can be made, especially considering a high market penetration that would allow for the C-ART concept to be fully implemented. These assumptions are elaborated in section 2.3, together with some potential C-ART scenarios and a first description of the C-ART system. Before that, a description of the levels of automation is provided.

## 2.2 Classification of levels of automation

The International Society of Automotive Engineers (SAE) delivered a harmonised classification system for Automated Driving Systems (ADS), specifically *SAE J3016*

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<sup>(1)</sup> In the transport community also known as the Braess' paradox (Braess, 1969).

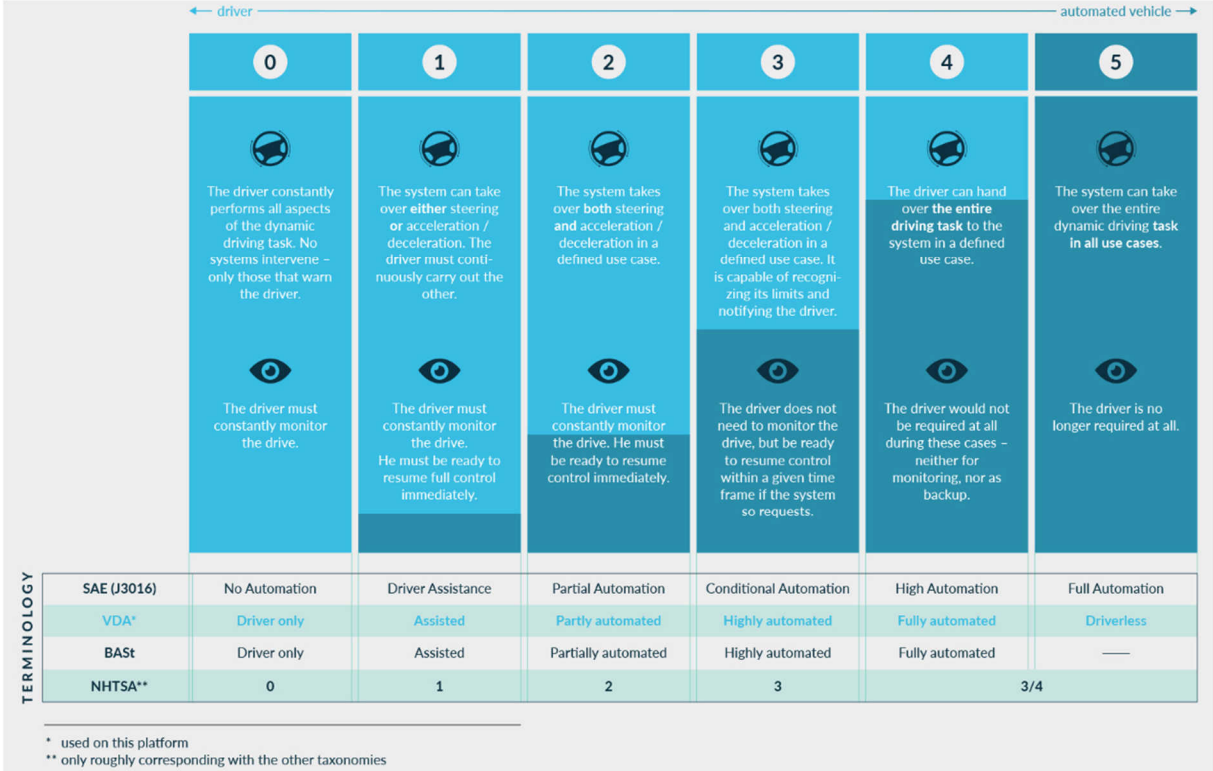
<sup>(2)</sup> Similar to what happened in China where the quick evolution of car-ownership is increasing the magnitude of extreme traffic events (BBC, 2010).

<sup>(3)</sup> Like those demonstrated in the European Union's CityMobil2 project (CityMobil2 website <http://www.citymobil2.eu/en/>, last accessed 10 January 2017).

*Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems* (SAE International, 2016). SAE J3016 was first issued in January 2014 but has been revised in September 2016 relying on lessons learned from stakeholders' discussions, as well as from research projects conducted in Europe (AdaptIVE) and the United States (Crash Avoidance Metrics Partnership - CAMP Automated Vehicle Research - AVR). Although other classification systems exist (NHTSA, 2013; BAST - Gasser, 2012; VDA, 2015; see Figure 1), the SAE classification for automated driving systems seems to be the most widely adopted taxonomy.

This Recommended Practice provides a taxonomy describing the full range of levels of driving automation in on-road motor vehicles (see Figure 2). These levels primarily identify whether it is the human or the machine in charge of the Dynamic Driving Task (DDT), ranging from level 0 where the DDT is entirely performed by the human driver (no automation) to level 5 where the DDT is entirely performed by the automated driving system (full automation). The intermediate levels represent a shared performance of the DDT between the driver and the vehicle, either in a simultaneous or in a sequential way. The DDT comprises both the lateral control (steering) and the longitudinal control (accelerating, braking) of the vehicle, together with the monitoring of the environment, referred to as Object and Event Detection and Response (OEDR). As specified in SAE J3016, "these levels are descriptive rather than normative and technical rather than legal. They imply no particular order of market introduction. Elements indicate minimum rather than maximum system capabilities for each level. A particular vehicle may have multiple driving automation features such that it could operate at different levels depending upon the feature(s) that are engaged."

**Figure 1.** Equivalences of driving automation classification systems



Source: 2025AD, 2015 (Copyright © 2015 Continental AG).



**Figure 2.** Summary of SAE international’s levels of driving automation for on-road vehicles

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
<b>Human driver monitors the driving environment</b>						
<b>0</b>	<b>No Automation</b>	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
<b>1</b>	<b>Driver Assistance</b>	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
<b>2</b>	<b>Partial Automation</b>	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	<b>System</b>	Human driver	Human driver	Some driving modes
<b>Automated driving system (“system”) monitors the driving environment</b>						
<b>3</b>	<b>Conditional Automation</b>	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	<b>System</b>	Human driver	Some driving modes
<b>4</b>	<b>High Automation</b>	the <i>driving mode</i> -specific performance by an automated driving system of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	<b>System</b>	Some driving modes
<b>5</b>	<b>Full Automation</b>	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	<b>All driving modes</b>

Source: SAE International, 2014 (Copyright © 2014 SAE International).

The levels of automation defined in SAE J3016 are the following (indicating examples of currently available systems in levels 0-1 and future potential systems for levels 2-3-4-5<sup>(4)</sup>):

— **Level 0 – No automation:**

The driver is responsible for performing all the DDTs (longitudinal and lateral control plus monitoring of the environment) on a sustained basis during the journey.

Examples: *Anti-lock Braking System (ABS), Electronic Stability Control (ESC), Advanced Emergency Braking System (AEBS), Lane Change Assist (LCA), Park Distance Control (PDC), Lane Departure Warning (LDW), Forward Collision Warning (FCW)*. Although level 0 is defined as “no automation”, two kinds of systems intervening without the input of the driver fall in this category, namely warning systems (e.g. LCA, PDC, LDW) and emergency systems (e.g. ABS, ESC). Although emergency systems actually provide lateral and/or longitudinal control under specific situations (e.g. when braking), they intervene for short and non-sustained periods and therefore are considered non-automated.

— **Level 1 – Driver Assistance:**

Automated systems of Level 1 execute parts of the DDT (longitudinal or lateral control). The human driver is responsible for the remaining aspects of driving, including OEDR, supervision of the automated DDT, execution of the DDTs that are not automated and activation or deactivation of the assistance systems.

<sup>(4)</sup> For systems’ definitions, please see List of abbreviations and definitions at the end of this report and the following references (OECD/ITF, 2015a; Gleave et al., 2016; ERTRAC, 2015; Bartels et al., 2015).

Examples: *Adaptive Cruise Control (ACC), ACC including stop-and-go function, Cooperative ACC (CACC) Platooning, Lane Keeping Assist (LKA), Park Assist (PA).*

— **Level 2 – Partial Automation:**

These systems execute parts of both the longitudinal (accelerating/breaking) and lateral (steering) control. The driver is responsible for OEDR, supervising and activating/deactivating the automated systems. Under this level, the driver could be disengaged from physically operating the vehicle in certain circumstances (e.g. allowing hands off the steering wheel). Nevertheless, there is a constant need to monitor the driving environment and be able to immediately take full control of the vehicle when necessary.

Examples: *Park Assist Level 2, Traffic Jam Assist.*

— **Level 3 – Conditional Automation:**

Level 3 systems are able to perform all the aspects of one or more DDTs and safety functions, including monitoring of the driving environment, under certain conditions (e.g. traffic jams on motorways). The driver is not required to constantly monitor the automated DDTs while the Level 3 system is active, but needs to be able to take over control with appropriate reaction time when required. Thus, the system needs to alert the driver in advance if conditions require transition to driver control.

Examples: *Traffic Jam Chauffeur, Highway Chauffeur, Truck Platooning.*

— **Level 4 – High Automation:**

Level 4 systems perform all the aspects of the DDTs under specific conditions in a similar way to level 3 systems but with the difference that systems under level 4 do not require a human driver to provide fall-back, as they are capable of initiating deactivation when design conditions are no longer met and fully deactivating in cases where the driver takes control or a minimal risk condition is achieved. As a consequence, the driver might perform secondary actions, even those requiring a long reaction time, while the automated mode is active. Full automation in certain driving scenarios, particular routes and low speeds. It is where the “everything somewhere” strategy begins.

Examples: *Parking Garage Pilot, Highway Pilot, Highway Pilot with ad-hoc Platooning, Cyber Cars, Cyber Vans, Cyber Minibuses, High-Tech Buses, Personal Rapid Transit (PRT), Advanced City Cars (ACC), Dual-mode Vehicles.*

— **Level 5 – Full Automation:**

Automated systems of level 5 are capable of performing all aspects of the DDTs under all roadway and environmental conditions. Therefore level 5 systems can cover all driving modes that can be managed by a human driver: i.e. all geographic areas, all roadway types, all traffic conditions, all weather conditions, all events/incidents. These are the only automated systems that can be properly named “self-driving vehicles”, “driverless vehicles” or autonomous vehicles”.

Examples: *Fully automated cars and trucks, Automated Taxis.*

The shift from partial automation (Level 2) to conditional automation (Level 3) represent a significant leap from a technical and conceptual perspective, as at this point the complete DDT including lateral and longitudinal control and OEDR is to be performed by the ADS, the driver being only required to resume control if the system falls out of its scope of operation.

Nonetheless, there are some critiques on this kind of classifications (Templeton, 2014). One reason is that defining an ordered sequence of levels suggests that a hierarchy in the technology exists and creates an expectation of evolution in this direction when in reality it is not possible to predict the actual path that a technology will follow. Furthermore, the definition of the ultimate level (full automation) when the technology is not yet mature

enough, prejudices the evolution in automated driving. As stated in (Di Febraro and Sacco, 2016), “*Full automation*” is the future of road transport, but the transition from manual to fully automated vehicles is especially dependent on the interactions between humans and automation, but also between automated vehicles and manual vehicles, and between automated vehicles and infrastructure. SAE classification implies that for levels 0 to 3 the functionalities are already present in many vehicles while it is obvious that in order to reach the “only autonomous vehicles” scenario there are many obstacles to be gradually surpassed including the interaction between human behaviour and automation, automation and infrastructure and automation with other traffic flow components.

The introduction of highly automated driving functions will probably take place incrementally and in an evolutionary way, with first systems introduced in specific contexts and scenarios of lower complexity (e.g. motorway driving) and gradually covering broader and more complex driving situations. According to the Automated Driving Roadmap published by the European Road Transport Research Advisory Council (ERTRAC) (ERTRAC, 2015), there are still many challenges to overcome in various areas ranging from environment perception capabilities of sensor systems, vehicle dynamics, functional safety, testing and certification, human machine interaction, monitoring strategies up to new aspects of product liability. A big challenge is the handling of the transition period with mixed traffic participants.

## **2.3 Motivation for a C-ART system**

This section draws on an analysis of the plausible effects of AVs on the mobility, safety and environmental realms. By analysing the key aspects that may have an influence in the implementation of AVs, future plausible pathways are outlined, motivating the need for a C-ART-based solution. The focus is not on making predictions, but rather on reflecting what might be plausible, which has become the state-of-the-art methodology in futures research (Trommer et al., 2016).

Firstly, a view to the potential AVs deployment pathways is given, analysing different possible projections. Then, the overall advantages and disadvantages of these technologies are listed. A description of the fundamentals governing the future effects of automated and connected vehicles on the transport system is provided next. Eventually, on the basis of these fundamentals, plausible impacts in two timeframes are analysed.

### **2.3.1 AVs deployment scenarios**

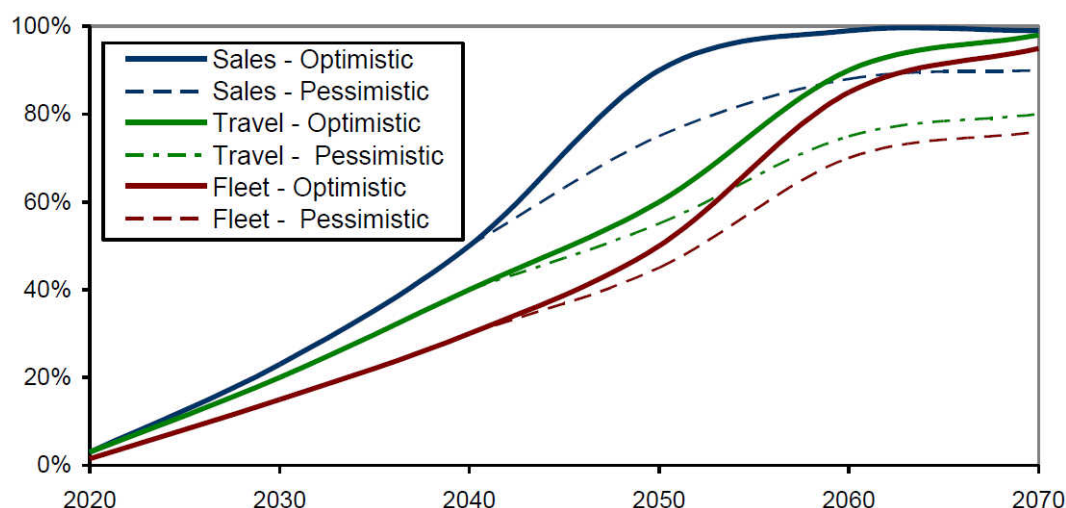
Optimistic estimates have anticipated that AVs will account for up to 75% of cars on the road by the year 2040 (IEEE, 2012) or even, that by 2030 all vehicles will be self-driven, plus electric and car shared (Seba, 2016). Other estimate of AVs penetration indicate a 30% penetration rate by 2040 (Litman, 2016). In a 2016 envisioning work about the impacts of AVs, it was assumed that AVs could account for a 50% by 2040 (with 90% private vehicles) and reach a 100% by 2060 (with 70% private vehicles) (Chapin et al., 2016) <sup>(5)</sup>. Research firm IHS Automotive predicts that there will be 21 million AVs on the road by 2035 (4.5 million in the US) (Korosec, 2016).

According to Litman (Litman, 2016), as it has been the case of other vehicle technologies, AVs could take 1 to 3 decades to dominate vehicle sales and 1 to 2 decades to dominate vehicle travel and even at market saturation, a significant part of vehicles and vehicle travel may still be human-driven (dashed lines in Figure 3, i.e. pessimistic projections). For instance, as represented in the figure, AVs could represent around a 15% of the vehicle fleet by 2030 and around 45% by 2050. These projection curves serve as a basis for the subsequent analysis of potential effects of automated and connected vehicles.

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<sup>(5)</sup> This was an assumption for purposes of a set of visioning sessions, drawn from the available literature.

**Figure 3.** AVs sales, fleet and travel projections (optimistic versus pessimistic)



Source: Litman, 2016.

### 2.3.2 Overall impacts of AVs

The impacts of AVs on the transport networks are still unknown, difficult to be estimated and require further research in the next years. Nonetheless, some preliminary estimations have been made in different studies (e.g. Anderson et al., 2016; Fagnant and Kockelman, 2015, Litman, 2016) and are qualitatively summarized in Table 1. An analysis of specific impacts on mobility, safety and environment is provided in the following subsections, explaining the fundamentals of how the road transport system could respond to these technologies and devising future plausible scenarios where some of those impacts are particularly relevant. Many of these impacts are subject to the use of high levels of automation.

**Table 1.** Overall potential impacts of AVs

POSITIVE	NEGATIVE
<b>Safety</b> (↓ crashes due to human error)	<b>Safety</b> (↑ crashes due to new risk situations e.g. human factors issues in SAE level 3 systems, risk compensation, system failures)
<b>Environment</b> (↓ energy use / fuel consumption due to increased fuel efficiency and ↓ pollution due to reduced fuel consumption)*	<b>Environment</b> (↑ energy use / fuel consumption and ↑ pollution due to increased traffic)
<b>Mobility</b> (↓ congestion due to e.g. less delays that result from accidents, ↑ road capacity due to platooning, ↑ users e.g. young, elderly, disabled)	<b>Mobility</b> (↑ congestion due to increased travel demand, ↓ public transport)
<b>Security</b> (↓ criminal and terrorist activities thanks to vehicle control)	<b>Security</b> (↑ criminal and terrorist activities through hacking) <b>and privacy</b> (↑ risks of access to personal data)

POSITIVE	NEGATIVE
<b>Value of time</b> (↑ leisure time) <b>and comfort</b> (↓ driver stress, possibility to rest or work)	<b>Flexibility/joy/skills</b> (↓ flexibility to take instantaneous journey decisions, ↓ joy of driving, ↓ driving skills)
<b>Costs</b> (↓ labour costs of taxis and commercial vehicles as drivers are no longer needed, ↓ crash costs if crashes are reduced, ↓ insurance costs if crashes are reduced, ↓ parking costs if cars can be parked in less space and located in less expensive land, ↓ car ownership costs)	<b>Costs</b> (↑ vehicle equipment costs, ↑ infrastructure equipment needed, ↑ maintenance costs) <b>and revenues</b> (↓ parking revenues for cities)
<b>Business</b> (↑ new business opportunities based on e.g. new mobility services, ↑ productivity)	<b>Jobs</b> (↓ jobs like taxi/truck/bus drivers and crash economy, ↓ vehicle repair demands if crash rates reduce)
<b>Land use</b> (↓ parking spaces and they can be located outside city centres, ↑ green spaces)	<b>Land use</b> (↑ sprawled development patterns as a result of lower Value of Travel Time)

\* further benefits with electric and lighter vehicles

Source: Own elaborations.

Globally speaking, these impacts will probably come along a shift from a product model to a service model, in such a way that individuals are likely to pay for certain services on a sustained basis, e.g. software system updates (Smith, 2014). “*The automated vehicles of the future may be co-piloted by companies as much as they are by computers*” (Smith, 2014). AVs could also involve a change from car ownership to mobility on demand services (i.e. cars as a service). Cars as a service could offer the same level of service than the one offered by car ownership but at a much reduced cost, namely 10 times cheaper (Seba, 2016). The asset utilisation will increase manifold from a roughly 4% (as vehicles are parked 96% of the time) to around 90% of the time.

### 2.3.3 Underlying fundamentals of road transport system responses to AVs

To better understand the possible road transport system responses with the introduction of AVs, this subsection explains the fundamentals under increases or decreases of travel demand and road capacity. Clearly, the effects will differ over time as a consequence of numerous factors enabled by higher market penetration of automated driving technologies, which are summarised herein.

*Travel demand* can suffer variations in two directions, i.e. increasing or decreasing, with AVs (see Table 2). As a consequence of them making road travel cheaper, more comfortable, more efficient and accessible to new user groups, travel demand could potentially increase. This demand corresponds to both latent demand from these new (underserved) groups of users and induced demand resulting from capacity improvements enabled by AVs (the so called “rebound effect”). Other factors such as an increased urban sprawl, automated taxis or a lower use of public transport would also increase travel demand. Conversely, shifting to a shared mobility system could reduce vehicle ownership and travel demand.

**Table 2.** Potential positive and negative effects on total Vehicle Miles Travelled (VMT)






Influencing Factor	Increases VMT	Decreases VMT	Likely Automation Level
Rebound effect	X		2, 3, 4
Car-sharing and reduced vehicle ownership		X	2, 3, 4
Driverless taxis	X		4
Greater sprawl	X		2, 3, 4
Substitute for intracity or intercity public transportation	X		4






Source: Anderson et al., 2016 (© Copyright 2016 RAND Corporation).

On the supply side, *roads capacity* may also vary in both directions. Initial stages of AVs deployment may actually decrease throughput as a result of their cautious behaviour, and inefficient interactions with human-driven vehicles and other road traffic participants. With a higher penetration rate of AVs coupled with vehicle cooperative features, capacity improvements are expected, since these vehicles could adopt shorter headways (e.g. platooning), provide a better traffic distribution using real time traffic information and reduce the number of disruptions to traffic flows.

What remains to be ascertained is how these two variables, demand and supply, relate to each other once AVs are introduced. The following table (Table 3) analyses the main impacts and characteristics of the possible developments in the relationship between road transport demand and supply.

**Table 3.** Main potential impacts and characteristics of different demand-supply developments

		SUPPLY (Roadway capacity)	
			
<b>DEMAND</b> (Travel demand)		 Car ownership prevails, throughput improves <i>EXPECTED IMPACTS: unclear effects on congestion (it is uncertain if the improvement in capacity can accommodate the increase in travel demand), but initially it is expected that fuel consumption/energy use increases and emissions increase</i>	 Car ownership prevails, throughput decreases <i>EXPECTED IMPACTS: congestion increases, fuel consumption/energy use increases, emissions increase</i>

	<b>SUPPLY</b> (Roadway capacity)	
		
	 Shared mobility prevails, throughput improves <i>EXPECTED IMPACTS: congestion decreases, fuel consumption/energy use decreases and emissions decrease</i>	 Shared mobility prevails, throughput decreases <i>EXPECTED IMPACTS: unclear effects on congestion (it is uncertain if the lower travel demand can be accommodated in a lower capacity scenario), but initially it is expected that fuel consumption/energy use decreases and emissions decrease</i>

Legend:

 Unknown  Positive  Negative

Source: Own elaborations.

If travel demand increases, congestion <sup>(6)</sup>, fuel consumption/energy use and emissions may increase. The increase in travel demand can be accompanied by an increase in road capacity, although the rate of each respective growth can differ and thus effects on congestion are uncertain. Conversely, if travel demand decreases, the opposite effects can be expected, i.e. decreases in congestion, fuel consumption/energy use and emissions. But similarly to the case of higher travel demand, the rate of each respective reduction (demand and supply) can differ and thus effects on congestion are uncertain.

In the short term, capacity improvements are not expected but the opposite, and travel demand may not increase particularly (as highly automated vehicles may not be available or if available, they may not be widely spread). In the long term, though, both capacity and demand improvements might be expected but it is unclear if the increased travel demand would outweigh the increase in road capacity. Given that roadway capacity is limited, there is the need to consider different approaches and technologies that avoid congestion and optimise the use of the networks. Among those solutions to congestion, there are the following: increasing supply (e.g. building new roads, increasing capacity thanks to automated and connected vehicles), decreasing demand (e.g. encouraging shared mobility, adopting roads pricing schemes) and possibly other demand management strategies like C-ART. An analysis of the specific impacts which may be expected in the next years/decades is made in the next subsection.

### 2.3.4 Expected impacts of AVs in the short, medium and long terms

We differentiate two timeframe scenarios: SHORT TO MEDIUM TERM (2020-2030) and MEDIUM TO LONG TERM (2030-2050). For each of these, an analysis of aspects like market penetration rates of AVs, safety, road capacity, travel demand and eventually congestion is made, following the estimated sales/travel/fleet projections and the fundamentals explained in the previous subsections. The figure below (Figure 4) represents the potential

<sup>(6)</sup> Congestion occurs when serviceable demand approaches actual supply (HCM, 2010 as cited in Smith, 2012).



situation in which these aspects are not providing the expected benefits on the road transport system, as a result of no or inappropriate measures being taken.

**Figure 4.** 'What if' reflections that motivate the need for C-ART in short to medium and medium to long-terms



Source: Own elaborations.

#### **2.3.4.1 Expected impacts of AVs in the short to medium term (2020-2030)**

##### **1. AVs would represent a small portion of the overall vehicle fleet and they would need to interact with conventional human-driven vehicles for a long period of time**

In the short-term, it is likely that the proportion of AVs on the roads will not be significant. One reason for this will be the high prices of AV technologies, since even if they will likely become cheaper with mass production, they will probably be relatively expensive as they need to meet high manufacturing, installation, repair, testing and maintenance standards (Litman, 2016). In addition, subscription fees for special services (e.g. mapping) may be required.

Apart from the price of technologies, other two barriers might prevent AVs from being massively spread in a first stage: consumer acceptance and regulations. While there are increasingly more on road trials addressing users' interaction with automated driving technologies (e.g. Piao et al., 2016, Carlström, 2017), some attempts to theoretically assess users' acceptance of AVs have also been made through inter alia questionnaires and interviews (without any direct interaction with the AV systems). These studies reveal initial low levels of trust on the safety of these technologies (e.g. FIA, 2015<sup>(7)</sup>), concerns that AVs would not drive as well as human drivers (Shoettle and Sivak, 2014a) or uncomfortable feelings travelling in an AV (European Commission, 2015g; Tennant et al., 2016). Overall, studies have identified men as being more prone to feel comfortable with AVs (European Commission, 2015g) or showing a stronger intention to use and buy one (Payre et al., 2014). Generally, users' acceptance towards AVs is slowly improving, especially as people are starting to familiarise and experience more and more with the technologies (Giffi et al., 2017; Piao et al., 2016). Therefore consumers are gradually building trust on AVs which will eventually have an influence on the adoption rate of these technologies. Similarly, connected vehicles face potential barriers from the users' side, such as e.g. not being willing to connect their vehicles and being concerned about data anonymity or the possibility to decide when to be connected (European Commission, 2014b). Further details about these studies can be found in subsection 3.3.3.

<sup>(7)</sup> AA Populus poll based on 21,202 members answers (2012) (cited in FIA, 2015).



In addition to users' acceptance, regulation plays a key role in the spread of automated driving technologies. Automated and connected vehicles bring new challenges for regulators concerning among others traffic law, liability, security, access to data, protection of personal data. Work in these areas is ongoing at the moment in Europe and worldwide (e.g. European Commission, UNECE, NHTSA) and although no major legal obstacles exist for up to level 3 systems that will be commercialised around the year 2020, significant steps need to be done for the subsequent AV generations with higher levels of autonomy. Initial efforts by the regulatory bodies are placed at the development of a legal framework to allow AVs testing and afterwards, at the real operation of AVs on public roads (Trommer et al., 2016).

These factors, linked to the high average ages of vehicles on the road, indicate that there will probably be decades during which conventional vehicles and AVs would need to interact. This period could even last indefinitely as some people may want to drive only conventional vehicles (Schoettle and Sivak, 2014b as cited in Sivak and Schoettle, 2015b). In this mixed traffic period, conventional vehicles will interact with AVs of varying levels of automation (with probably more amount of those with lower levels of automation).

## **2. During these mixed traffic conditions, safety would not improve**

During the mixed traffic period, communication problems are expected between AVs and human driven vehicles. Conventional vehicle drivers' expectations about likely actions of surrounding AVs will be affected, mainly by the lack of eye contact feedback (Sivak and Schoettle, 2015b), and by reactions that are unexpected to human drivers. It is well known that most of the accidents involving Google cars have occurred due to the incapability of human drivers to anticipate reactions such as the sudden stop of the leading AV due to leaves or shopping bags fluttering on the road. Time will be needed for human drivers to understand how different AVs behave and therefore it is hard to believe that AVs will contribute to safety from the first moment they appear on the road.

AVs promise to fight back against those accidents where human errors are the main cause but it is not clear if they can compensate for crashes caused by inappropriate actions of other traffic participants (e.g. jaywalking pedestrians), vehicular defects (e.g. brakes failure), roadway factors (e.g. a pothole in the road), or environmental factors (e.g. fog) (Sivak and Schoettle, 2015b). As a result, AVs may not be safer than an average driver and may increase total crashes in the mixed traffic period (Sivak and Schoettle, 2015b). In (Schoettle and Sivak, 2015), it was found that AVs were involved in more crashes per million miles travelled than conventional vehicles although exposure was not sufficiently representative of the exposure of conventional vehicles. Other recent research found that AVs were involved in fewer crashes than conventional cars, especially for more severe crashes (Blanco et al., 2016 as cited in Townsend, 2016). In both studies, AVs which were involved in crashes were not at fault. The conservative behaviour of AVs could worsen the situation as they will tend to perform more cautiously compared to human-driven vehicles for safety and liability reasons. This circumstance may tempt human driven vehicles to adopt risky behaviours such as overtaking in dangerous situations or jumping in a platoon of AVs, thus introducing new risks. Mixed traffic of AVs and conventional cars may also have the following effect, as found out by (Gouy et al., 2014), where the short headways maintained by AVs running in a platoon may also be adopted by drivers of conventional vehicles. Another safety challenge of AVs will relate to their interaction with Vulnerable Road Users (VRU) such as pedestrians or cyclists and Powered-Two Wheelers (PTW) (Townsend, 2016). Besides, other potential new safety concerns are coming from cyberattacks, system failures, and offsetting behaviour (also referred to as risk compensation, meaning that additional risks are taken when users feel safer, e.g. reduced seatbelt use, less cautious behaviour) (Litman, 2016).

## **3. During these mixed traffic conditions, road capacity may be reduced and thus traffic efficiency would get worse**

AVs may reduce roads capacity in the near term, e.g. by maintaining large headways and thus reducing the available space for other vehicles, by reacting tentatively after yielding

or stopping (Smith, 2012). Some authors have found that different rates of connected and automated vehicles can improve the string stability of traffic flow, with automation likely being more effective than connectivity alone in preventing shockwave formation and propagation (Talebpoor and Mahmassani, 2016; see figure 5 of the original paper). Additionally, they found that throughput increases as market penetration rate of these technologies increases, with AVs resulting in higher throughput compared to connected vehicles at similar market penetration rates (see figure 15 of the original paper). Also, a recent study in the UK (Sabur, 2017) has estimated a rise in delays on motorways and major roads during peak periods by 0.9 per cent when a quarter of vehicles are automated. According to this study, congestion levels will not drop significantly until AVs make up between 50 and 75 % of the vehicles fleet.

#### ***2.3.4.2 Expected impacts of AVs in the medium to long term (2030-2050)***

##### **1. The number of AVs on the roads would significantly increase**

Private use of AVs could increase if prices become affordable for a wider part of the population, users trust and acceptance towards AVs increase and regulatory bodies provide the right set of measures. In addition to private AVs, the use of public automated transport solutions and AVs sharing/pooling travelling options could increase the proportion of ADS on the roads. Different estimates of AVs penetration in the coming decades have been made (e.g. IEEE, 2012; Seba, 2016; Litman, 2016), but a lot of uncertainty exists as to if and when AVs would reach a 100% penetration rate (see Figure 3).

##### **2. Travel demand would considerably grow**

Travel demand is expected to increase as a consequence of AVs making road travel cheaper, more comfortable, more efficient and accessible to new user groups. More specifically, some authors have estimated that the reduced cost of driver's time in AVs could result in an increase in light duty vehicle travel between 30% and 160% (MacKenzie et al. (2014) as cited in LaMondia et al., 2016), while others indicate changes in Vehicle Kilometres Travelled (VKT) ranging from a 4% increase for low-level automation to around 60% increase for high level automation (Wadud et al., 2016). Besides, AVs sharing among households could induce an increased travel per vehicle of up to 75%, according to some authors (Sivak and Schoettle, 2015a), even if vehicle ownership could be reduced up to a 43%. Shared AVs repositioning that result from AVs travelling empty to pick up passengers could increase travel distance by 11% compared to privately owned vehicles (Fagnant and Kockelman, 2014). Other estimates point at a total vehicle travel increase between 30% and 90% with mixed-fleets of shared AVs and traditional private cars, potentially also including a rise in the number of vehicles (OECD/ITF, 2015b). The increased travel demand from underserved groups (such as young, elderly, disabled, people with travel-restrictive medical conditions, people without a driving license) has been estimated in an annual 14% increase in VMT for the US population older than or equal to 19 years of age using light-duty vehicles (Harper et al., 2016). Other researches estimate that new user groups would result in an increase between 2% and 9% (Fagnant and Kockelman, 2015), 2-10% (Wadud et al., 2016) or even reach a 40% increase (Brown et al. 2014 as cited in Harper et al., 2016). Studies on user preferences have revealed some findings too. For instance, additional long-distance trips could be expected with AVs, especially given their higher sensitivity to costs and travel time compared to daily travel, and they could draw from personal vehicles and airplanes equally for trip distances below 500 miles (La Mondia et al., 2016). Moreover, at the local travel level, in those multimodal trips where the main mode of travel was done on a first class train, it was found an average preference for using AVs as last mile transport, compared to the use of other egress modes like bus, tram, metro and bicycle (Yap et al., 2016). As anticipated, though, the effects of vehicle automation could also yield opposite results to the ones just presented. For example, a decrease in VKT could be expected in the case of improvements in public transport or increases in urban density and car sharing. Factors such as less time spent searching for parking and higher occupancy resulting from a shared mobility would also have the potential to lower VKT (Brown et al., 2014 as cited in Wadud et al., 2016). Also, there is

some evidence that car sharing through car clubs results in reduced vehicle travel activities by members (e.g. Martin and Shaheen, 2011 as cited in Wadud et al., 2016).

### **3. Road capacity would increase with AVs**

As anticipated in point 3 of the previous subsection, some authors have found that both automated and connected vehicles have the potential to improve the throughput by more than 100%, with AVs resulting in higher throughput compared to connected vehicles at similar market penetration rates (Talebpour and Mahmassani, 2016). This might be possible thanks to the shorter headways that these technologies would facilitate, together with a better traffic distribution over the network enabled by real time travel information and a reduction in the number of small disruptions to vehicle flows and the rate of crashes and other incidents (Smith, 2012). As declared by (Smith, 2012), automation could ultimately have the same effects as adding a third, fourth or fifth lane to a highway. In contrast to these results, some authors have indicated that AVs could reduce road capacity if comfort sake users (e.g. users willing to work or rest during the ride) program their vehicles for lower acceleration/deceleration characteristics, given that passengers tend to be more sensitive to acceleration than drivers (Le Vine et al., 2015). These authors anticipate a tension in the short run between a more productive use of travel time and increased network capacity, at least in certain situations.

AVs are expected to facilitate an increased capacity but whether this increased capacity is going to be linked to an adequate use of the existing infrastructure remains unclear, especially considering that rural roads and neighbourhood streets, which make up for a significant proportion of existing roads, typically operate far below capacity whereas motorways, which account for just a small proportion of roads, operate at higher capacities (Smith, 2012).

In terms of the number of vehicles, Autonomous taxi (AT) fleets have the potential to take over a significant amount of traffic handled nowadays by conventional vehicles. Recently, some authors (Bischoff and Maciejewski, 2016) have found that one AT could replace the demand served by 10 conventionally driven vehicles in Berlin. Another study (Burghout et al., 2015) indicated that a Shared Autonomous Vehicle (SAV)-based personal transport system has the potential to provide an on-demand door-to-door transport with a high level of service, using 5% of today's private cars and parking places.

Travel choices are affected by increases in vehicles capacity, free flow speeds or perceived safety that result from a highway improvement (which could well be understood as the AV benefits in road capacity), leading to travel behaviour changes in time, space, mode, frequency, and destination, to name a few (Smith, 2012).

### **4. If demand increases faster than road capacity, congestion peaks may occur, representing as a consequence a threat for personal mobility and the environment**

Even if AVs have in the long term the potential to increase road capacity, the demand that would result from more vehicle use might require additional capacity needs (Fagnant and Kockelman, 2015) and may result in increases in congestion, energy use and emissions. According to (Smith, 2012), demand is likely to increase faster than corresponding capacity and is going to have significant consequences for the future physical and legal infrastructures. This author indicates that with the increased demand/capacity, highways may carry significantly more vehicles but average delay during peak period may not decrease appreciably. As stated in (Fagnant and Kockelman, 2015), it is possible that already-congested traffic patterns and other roadway infrastructure will be negatively affected as a consequence of the additional travel. On the contrary, the same authors state that the existing infrastructure capacity should be adequate to accommodate for the estimated new and/or induced travel demand, thanks to the congestion mitigation features of AVs, the increases in effective capacity and investments of V2I infrastructure. A recent study found reductions in global network congestion with the introduction of AVs (Di Febbraro and Sacco, 2016), although it did not account for the potential increases in travel demand. Additionally, although safety benefits are expected with higher levels of

automation, some authors argue that these benefits may not be as large as initially foreseen (Sivak and Schoettle, 2015b) and consequently, the improvements in traffic congestion due to a reduction in the number of accidents may be overestimated. Besides, an interesting viewpoint is the following which points out that the lower Value of Travel Time (VTT) induced by an increased comfort during travelling in an AV may make people less sensitive to congestion problems, as far as congestion times are concerned (Correia and van Arem, 2016). However, some tested scenarios of this study gave the opposite result suggesting that a lower VTT provides new route opportunities thus breaking up traffic and creating less delays.

Regarding fuel consumption, energy use and CO<sub>2</sub> and pollutant emissions, the general opinion is that AVs will make the system cleaner and more efficient. Fuel economy could be improved by a smoother acceleration and deceleration than the one of human drivers, which has been estimated at a 4–10 % (Anderson et al., 2016). The so called platooning enables shorter distances between vehicles, lower peak speeds, and can reduce the air drag of following vehicles, thereby reducing the amount of consumed fuel as well as improving travel times. Also, decreases in car crashes could eventually lead to lighter vehicles with lower fuel consumption and thus less polluting. Further reductions in pollution can be expected with the use of alternative fuels and electric vehicles that might be enabled by AVs (especially in view of the lighter vehicles). However, in the light of the additional demand, it is uncertain if the decline in fuel consumption and emissions enabled by AVs would actually outweigh the increased consumption and emissions resulting from the rise in travel demand (Anderson et al., 2016). In this context, a publication by (Smith, 2012) indicates that emissions per vehicle kilometre travelled may decrease but total emissions along a day may actually increase.

The implementation of demand-management strategies could become necessary to manage the effects of the increased travel demand (Smith, 2012). These strategies can comprise: internalization of the costs of travel (e.g. through roads tolling, VKT fees, carbon taxes), limiting suburban sprawl or optimizing urban circulation (e.g. through tolling or parking fees) (Smith, 2012). Fagnant and Kockelman (Fagnant and Kockelman, 2015) pointed out that technical and implementation challenges such as city or region-wide coordinated vehicle-routing paradigms and protocols are forthcoming in order to realize the full potential of high adoption AV shares. Mahmassani (Mahmassani, 2016) raised, among other key motivating questions for the study of the operational implications of automated and connected vehicles on transport and mobility, one question on what kind of controls agencies should be contemplating. The author discusses three control measures to improve the efficiency and quality of traffic flow: reserved lanes for automated and/or connected vehicles, speed harmonization and intersection control, each of which presents different challenges and impacts. The operation of the transport system will remain a challenge in the next decade. Given the incredibly large amounts of valuable data that will be available, the author acknowledges the need to work towards the access and integration of such data for all aspects of transport planning, operations, management, and policy making. Recently, Carlos Ghosn, the CEO of car company Renault, stated that the fact that full automation will make it possible to do everything in the car will increase travel demand to a point that may require to build some kind of air traffic control for the roads to take over when needed (Gandel, 2017).

These background data outlines both short and long distant plausible scenarios where a C-ART solution as the one being investigated in the C-ART study could be beneficial. Further research is needed to deepen the understanding of such a C-ART solution, the potential barriers to its implementation as well as on possible design criteria.

## **2.4 C-ART scenarios**

This section proposes a set of scenarios for the C-ART system under development. It takes into consideration the findings from previous subsections about the expected impacts of AVs in the short, medium and long terms.

Thus, two C-ART scenarios can be projected corresponding to the two timeframes analysed beforehand:

— Short to medium term scenario (2020-2030): **C-ART 2030**

AVs account for a small percentage of vehicle fleet and coexist with conventionally driven vehicles. Safety is not enhanced. Road capacity is reduced in this scenario.

C-ART will provide coordination of AVs in some parts of the road transport network (e.g. on specific highways). AV users would thus need to decide whether they want to access the C-ART network at a given point in time. In this decision making process, users could rely on updated information about the status of the C-ART network, showing e.g. estimated entry time, estimated travel duration, estimated fuel consumption and emissions reduction, etc. If users accept to drive through the C-ART network, they will receive an assigned time slot for network access which will depend on the current use demand. They will be navigated to the access point of the C-ART road to be used. This scenario may require the existence of specific infrastructure areas at entry points to facilitate the access of AVs to the network. When leaving the C-ART network, passengers in AVs or vehicle owner/manager will receive a message with real consumption data, showing how C-ART has contributed to a more sustainable mobility.

Expected C-ART impacts: A C-ART system could provide partial benefits in such a scenario, as it will be possible to implement it in just a part of the whole road transport network. For vehicles travelling through the C-ART network, reductions in fuel consumption and emissions would be expected.

— Medium to long term scenario (2030-2050): **C-ART 2050**

AVs represent a substantial portion of road transport, almost achieving a 100% penetration rate. Travel demand increases significantly in this scenario. Road capacity is also increased but cannot satisfy the increased demand in certain points of the network.

C-ART will coordinate AVs along their complete journeys. No decision making will thus be needed on the side of the users. The C-ART system will manage the existing demand at a given time and will thus allocate AVs to different routes, optimising safety, fuel consumption and travel duration in real time. The use of fast and reliable algorithms for real time C-ART criteria calculation will make it possible to organise traffic in the best way possible, without penalising any user.

Expected C-ART impacts: Further benefits would be possible with this scenario, where C-ART would be able of controlling the whole road transport network. AVs would smoothly flow over the roads, minimising their environmental impact while providing safety and comfort to C-ART users.

For each of these two C-ART scenarios, two personas <sup>(8)</sup> are described to help in creating a vision of the future, illustrating the key motivators, needs and goals:

— *C-ART 2030: **Pierre**, France, 50 years old, truck fleet owner*

Pierre owns a fleet of commercial vehicles for transporting goods between some of the main cities in France (e.g. between Paris and Lyon). There are certain fixed routes that are driven on a daily/weekly basis. Motivated by the wish to reduce the company's operational costs, he acquired several highly automated commercial trucks for the longest routes. He is an early adopter of technology and trusts the positive impacts it can bring to individual users and society as a whole. As soon as a C-ART network became operative for several national highways, he instructed his trucks/workers to follow them regularly. Not just because he acknowledges the fuel consumption and environmental advantages of using these roads, but also because the government

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<sup>(8)</sup> Precisely, these are just approximations to what a persona (Goodwin and Cooper, 2009) would actually be in the context of interaction design, but used herein mainly for illustration purposes.

incentivises driving on these roads with a tax reduction. He quickly realised the benefits of using the C-ART network, especially compared to normal roads where still a significant amount of conventional vehicles exist and traffic flows are sometimes heavily affected.

This persona illustrates a COMMERCIAL VEHICLES scenario.

- *C-ART 2030: **Sonja**, Austria, 23 years old, student and user of mobility-on-demand*

Sonja does not own a private vehicle. She is studying environmental sciences at the University of Vienna. And whenever she needs to travel in and out of the city, she relies on car and ride sharing programs with highly automated electric vehicles which are efficiently working since years. She often travels to Graz where her boyfriend lives and the sharing program she normally uses for these trips is committed to further increase its environmental performance by selecting the most optimal routes. This implies the use of C-ART highways, where traffic is coordinated centrally for an optimisation of energy consumption and emissions, amongst others. She knows the electricity reduction enabled by the use of these roads as the automated electric car she travels in displays this information by the end of the trip. And she is particularly enthusiastic about this as she strongly cares for the environment.

This persona illustrates a MOBILITY AS A SERVICE/SHARING scenario, short distances on weekdays but longer during weekends/holidays.

- *C-ART 2050: **Natasha**, Latvia, 65 years old, professor at university*

Natasha teaches physics at the University of Riga but lives outside of the Latvian capital, in the city of Jurmala. She owns an automated vehicle that she uses to commute to her workplace everyday, which has been especially useful for her after the tragic event she suffered five years ago, when her vision was significantly impaired because of a too late diagnosed glaucoma. Since some years traffic has started to be coordinated through a central management system and depending on the current traffic circumstances, the system decides which is the most optimum route to follow to your destination. Natasha knows that her trip to and from university in the morning rush hour can take between 30 and 40 minutes depending on the system's decisions which in turn depend on travel demand. But she travels in full comfort and confidence in her travel time, as excessive delays are rare.

This persona illustrates a PRIVATE VEHICLE/OWNERSHIP scenario.

- *C-ART 2050: **Magnus**, Sweden, 40 years old, worker at a telecommunications company and long-distance infrequent commuter*

Magnus lives in the Swedish city of Halmstad but works in Gothenburg. He moved there five years ago with his family, when their third child was born and they were searching for a bigger house to live in. The around one-hour commuting time needed to come to his company's office was not a hurdle in deciding to move there, especially because he can work from home most of the time and was already a frequent user of on-demand travel services which are convenient and much cheaper than other transport solutions and because automated vehicles allow him to use his travel time valuably. His family just has one big minivan that they normally use for family holidays. For his infrequent commuting trips he requests the ride sharing service just some minutes before he needs to leave. Immediately after the request is made, he receives a confirmation message with the estimated arrival time, calculated by the central road transport management system. He is happy to share the trip with other passengers that travel to the same destination or through the same route as he still has some privacy and can work during the trip, thereby not caring in particular if the trip is slightly longer.

This persona illustrates a MOBILITY AS A SERVICE/SHARING scenario, with long commuting distance.

## 2.5 Building the C-ART concept

After a short review of the history of AVs, some past studies of relevance in the framework of C-ART are analysed. With this background information and the previously devised scenarios, a first definition of the C-ART system is given.

The fully automated car received its first screen appearance in the American road safety education film *The Safest Place* (1935): "*The vehicle always stays in its lane, never forgets to signal when turning, obeys all stop signs and never overtakes on dangerous corners*" (Kröger, 2016). At this point in time, automated driving moved away from initial attempts to remotely control vehicles towards a guiding principle of an automated transport system. In 1939, at the World's Fair, GM's Futurama featured a model of future transport systems with automated highways in an imagined world of 1960 (Weber, 2014). Americas Independent Electric Light and Power Companies placed an advertisement in a 1956 LIFE magazine along with the motto "*Electricity may be the driver*" (Weber, 2014). Later on, the focus was shifted to providing the vehicle itself with automation capabilities rather than the infrastructure, motivated by economic and regulatory reasons. As the technology was quite far from development most of the publications of that era were focused on the control of the vehicles and not on their coordination in the transport network. As an example, Chiu (Chiu, 1979) proposed in 1979 a state-constrained vehicle-following approach for the longitudinal control of vehicles in an automated guideway transit system. A locomotion control method for AVs was proposed some years later by Kanayama et al. (Kanayama et al., 1988) in order for the control system to act as a flexible interface between the path-planner and the motor-wheel system. Other several AV navigation-related techniques (McGillem and Rappaport, 1989; Daily et al., 1988; McGillem and Rappaport, 1988; Wilfong, 1989; Kutami et al., 1990; Kehtarnavaz and Sohn, 1991, Chien and Ioannou, 1992) were published until the beginning of 1990s when ADAS technologies started to evolve. In the years after, the evolution of ADAS paved the way for more complicated automated functionalities, while developments in the communication technologies led to connected vehicles, a couple of steps before fully automated driving and C-ART. Specifically, research in AVs began in the 1980s, based on advances in Artificial Intelligence (AI), Geographic Information Systems (GIS) and Global Positioning Systems (GPS) (Gleave et al., 2016). During the 1990s, AVs for military purposes were promoted in the United States. From the 2000s automotive manufacturers started designing and testing their own models of AVs. A significant impulse was given by the Defense Advanced Research Projects Agency (DARPA) which established the Grand Challenge in 2004 as an incentive-based program to foster the development of AV technologies (Williams, 2015). Although no one was able to finish this first challenge, it helped to establish a community of innovators, engineers, programmers and developers in the field. A third event was held in 2007 focusing on an urban environment, namely the DARPA Urban Challenge. Defence and commercial applications appeared after these challenges. More recently, research on AVs received a stronger impulse from the launch, in 2009, of the Self-Driving Car Project<sup>(9)</sup>. Although full automation is not yet a reality, the presence of different cars travelling alone on public roads in California pushed researchers to work on the impact of self-driving vehicles on traffic flow from very different perspectives. Just as an example, in (Norman, 2014), the author imagines a future in which the Google car has to take the driving license test. In a recent publication (Correia and van Arem, 2016), the authors deal with the demand assignment problem in the presence of AVs, while in (Alonso et al., 2011) the authors implemented and tested two scenarios with similar results that deal with the problem of several vehicles approaching an intersection. The proposed methods included a small number of vehicles with conventional and automated driving capabilities and they were designed to be general for two-way roads, and applicable to an unlimited number of vehicles.

Marinescu et al. (Marinescu et al., 2010) propose a slot-based approach that guarantees arrival times based on a proposed Traffic Management System (TMS). The idea is to assign slots to vehicles where a slot represents a time-space corridor negotiated among vehicles.

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<sup>(9)</sup> Called Waymo since December 2016, <https://waymo.com/>.

The idea was based on the extension of similar notions such as the one proposed by Ravi et al. (Ravi et al., 2007) and another proposed by Cahill et al. (Cahill et al., 2008), with the usage of slots having predefined behaviour and each vehicle driving in a slot should replicate the behaviour of its slot. The results of the evaluation using VISSIM and two different algorithms indicate that the slot concept can be used to provide guaranteed arrival times to vehicles driving on highways. However, the traffic demand is considered as constant, something that it is debatable and not deeply investigated when we talk about AV technology.

The TRAMAN21 (Traffic Management for the 21st Century) project is running at present with the main objective of developing fundamental concepts and tools that will pave the way towards a new era of future motorway traffic management research and practice. It suggests the possibility of having a traffic control system that decides to recommend (or even order) a given time gap between ACC-enabled cars with the aim of improving traffic flows and providing higher capacities when and where needed (Merrifield, 2017).

A coordination system of AVs within a roadway has been patented by Amazon at the beginning of 2017 (Curlander et al., 2017), under the name 'Lane assignments for autonomous vehicles'. The system generates lane configurations (e.g. travel direction, lane width, restrictions on types of vehicles) and roadway assignments (assigning e.g. a lane, a time range and a speed range for access to the roadway) depending on roadway status and data, requests made by AVs, a roadway cost function that relies on different factors to calculate the costs to use a given roadway and an outcome directive that searches to optimize certain parameters (e.g. maximise traffic flow, maximise speed of vehicles, maximise toll revenues).

On the basis of this background information, the C-ART system is described. C-ART is meant as an extension of the automated driving concept by adding communication capabilities that connect vehicles in between and with the infrastructure and adding a central coordination player that manages traffic on the basis of a set of criteria. These criteria can comprise e.g. fuel consumption and emissions, safety, travel time. Therefore C-ART is founded on highly automated and connected vehicles and a connected infrastructure. More specifically, C-ART relies on fully automated vehicles which are classified as level 5 according to SAE's taxonomy (SAE International, 2016).

C-ART is presented as the "ideal" transport system that provides AVs with a central coordination and regulation in order to manage their access and use of the road transport system. It is conceivable on the basis of advanced technological developments and a wide deployment of automated and connected vehicles, thereby representing a long distant scenario (at least, to be realized in its full dimension). The C-ART vision reflects a dual shift. First of all, a shift from conventional vehicles to AVs. Secondly, a shift from AVs to C-ART. A C-ART system could potentially strengthen the positive impacts of AVs while minimising the negative ones.

C-ART is more than just automated and connected driving, with the infrastructure being the entire transport system, which should be in the position to instruct the vehicle on more fundamental choices to take (e.g. the path to follow or the speed to maintain). This is an important conceptual novelty with respect to the current paradigms.

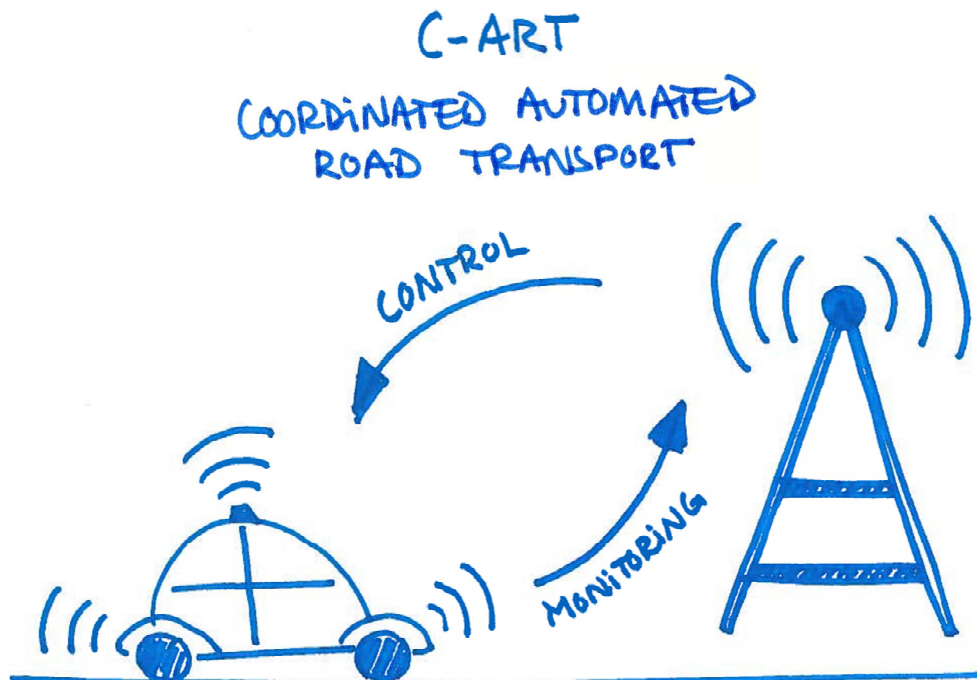
The data requirement for C-ART is an aspect that has not been fully explored yet. Recent research has shown that in order for the vehicles to travel in a fast and safe way, very detailed maps are necessary. These maps are currently under development by different companies. Defining clear data requirements for the C-ART can be an important outcome of the project.

As schematically presented in Figure 5, taking advantage of AVs' communication and automation capabilities, a Road Transport Management System (RTMS) can have the role to guide each vehicle through its entire journey with the objective to optimize the overall efficiency of the system. It is clear that C-ART requires that all vehicles must be automated and connected and that the RTMS is able to simulate in real time the movement of the AVs and their energy and fuel consumption as well as pollutant emissions in the case that these



variables are included in the optimization of the system. This implies that vehicle logics and operations are known to the RTMS (at least to a sufficient extent), which is certainly not expected to be the case at least for the next decade. In addition, it is assumed that a RTMS has sufficient capabilities to manage the tactical behaviour of thousands of vehicles and to ensure that none of them will be excessively penalized by the optimization of the system. It is therefore clear that a C-ART system needs to be seen with a long-term perspective, as most of the conditions for its introduction will not be available before at least 2040.

**Figure 5.** Control-monitoring loop of C-ART between AVs and RTMS



Source: Own elaborations.

Moreover, assuming that a central controller has the role of optimizing a certain transport system to minimize a combination of the overall travel time and costs, energy use, air pollution and risk of accidents, it will be necessary to have reliable, though inexpensive models able to evaluate the status of the transport system, its short-term evolution and the connected externalities in real-time. To this aim, traffic simulation models, fuel consumption and emissions models, pollutant dispersion models and collision risk models are necessary. Although many possible options in the different fields area available, an integrated solution going from traffic to pollutant concentration and risk of accidents does not exist yet.

Therefore the existing models need to be properly integrated and this is usually not a trivial task (with both modelling and software-related issues to be tackled). Research is therefore required to understand the need of the different models and to find a proper integrated solution. In addition, the estimation of CO<sub>2</sub> and pollutant emissions from vehicles and their concentrations with sufficient accuracy (but also with sufficiently simple models) is an issue deserving research, especially in an era in which electric driving and other fuel savings technologies will considerably affect the vehicles' impact on the environment. It will require the development of a technology-based fuel consumption and emission model as well as a dispersion model able to take into account the land morphology.

Finally, if an efficient and robust modelling framework for the simulation of the transport system and its externalities will be developed, the real-time optimization of the system

itself and the possibility to detect critical traffic situations (traffic situations with an increased risk of collision etc.) are two topics that will also require research.

Real-time traffic optimization is indeed a topic that has considerably attracted the attention of researchers in the last decade. Many solutions have been proposed, all suffering for the computational requirements and the sub-optimality of the solution found. The research will mainly focus on the latter point, as we expect that in 20-30 years the computation time will not be a problem any longer.

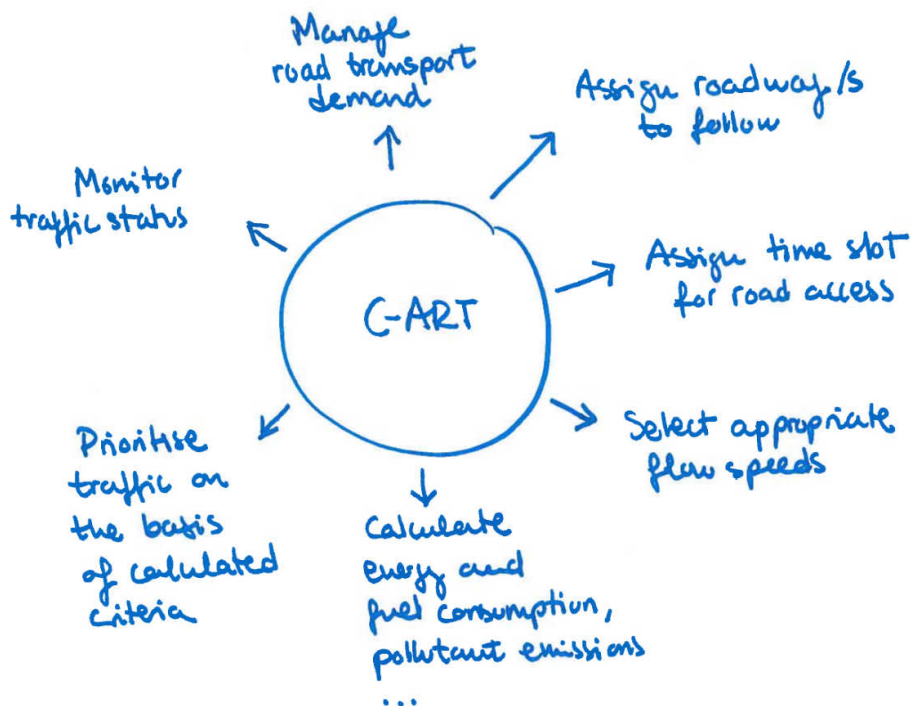
Concerning the real-time identification of the black-spots for road safety, the main challenge is to identify the right proxy of road safety in traffic conditions. Many researches have been carried out in the last years and the last proposals seem encouraging.

Once the model for simulating C-ART is available, different strategies for its optimization and for the localization of the critical situations can be adopted. Given the novel character of this activity, any result achieved on this point will provide a contribution on the state-of-the-art on AVs.

Two C-ART systems for the two projected scenarios:

- C-ART 2030: implemented on some roads
- C-ART 2050: implemented on the whole road transport network (functions illustrated in Figure 6)

**Figure 6.** Functional diagram of C-ART 2050



Source: Own elaborations.

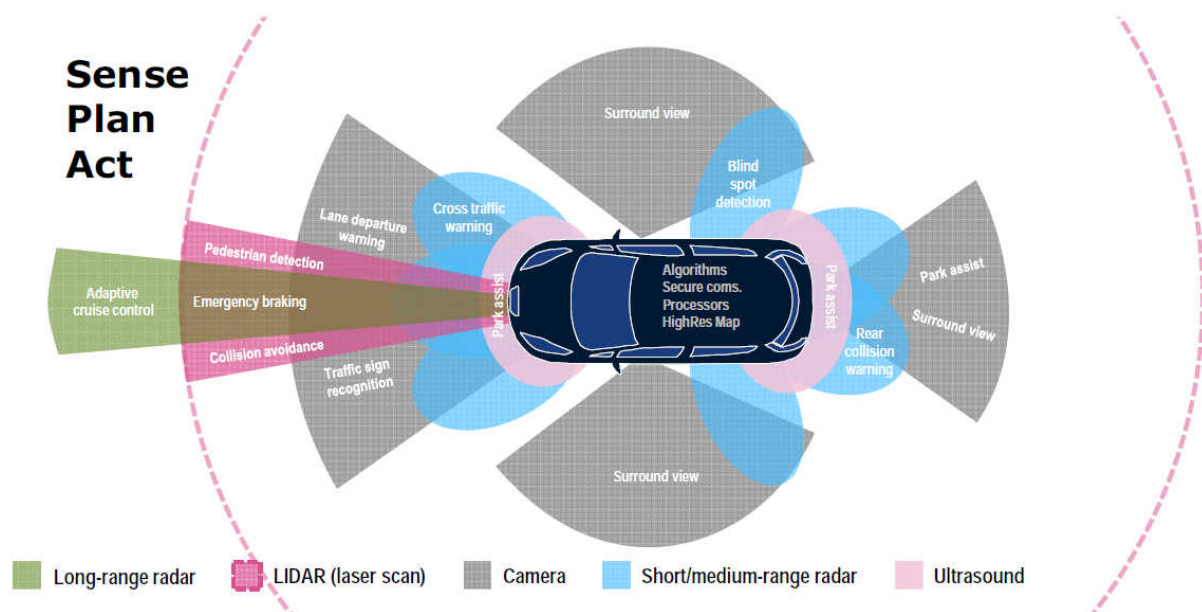
### 3 Defining the C-ART framework

This chapter defines a framework for C-ART, addressing some of the currently open questions on the basis of literature references and informal stakeholders’ feedback (obtained prior to the C-ART stakeholders’ workshop), specifically covering the following topics: technology, infrastructure, human factors, data, insurance and liability, ethics, policy and legislation. These topics are developed separately in the following subsections, sometimes including links among topics given their interdependences.

#### 3.1 Technology

AV technologies encompass hardware and software components including state-of-the-art sensors (namely ultrasonic, infrared, radar, lidar, GPS and Inertial Measurement Unit - IMU, camera vision systems, wheel and steering wheel encoders, throttle position and other control feedback sensors), sensor data processing technologies, high definition maps, decision and control algorithms and secure communications (see Figure 7). Instead, connected vehicles are equipped with Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication technologies. From a technical viewpoint, current technologies for highly automated driving in controlled environments are rather mature (OECD/ITF, 2015a).

Figure 7. AV technologies



Source: OECD/ITF, 2015a (© OECD/ITF 2015).

##### 3.1.1 AV technologies

Automated driving is correlated to the assistive functionalities offered to the driver and whether it is considered necessary for the driver to intervene or not. The path to full AVs and furthermore to C-ART is an evolutionary process involving several driver assistance functionalities starting with the Anti-lock Braking System (ABS), the Traction Control System (TCS), the Electronic Stability Control (ESC) (all of them intervene beyond human capability to act) and then evolving in terms of complexity, intelligence, efficiency, autonomy and cost with numerous other Advanced Driver Assistance Systems (ADAS). ADAS is a collection of many intelligent units integrated in the vehicle itself. All these units perform different tasks and support the human driving by informing, warning and in some cases actively intervening. ADAS technologies provide the tools for several functionalities in AVs related to safety, security, monitoring and communication within the same vehicle,

between neighbour vehicles and between the vehicle and the road infrastructure. Vehicles today are equipped with many ADAS systems of various intelligence that are capable of interacting with each other and which are controlled by the human driver, each of them taking care of some critical aspect of driving.

In the current state of the art, common ADAS technologies, which can be found in vehicles on the road today and offer driver support are Lane Change Assist (LCA) (also called Blind Spot Detection, BSD), Park Distance Control (PDC), Lane Departure Warning (LDW), Forward Collision Warning (FCW), all of them level 0 systems. The LCA system monitors the areas to the left and right of the car, including blind spot detection, and up to 50 metres behind it and warns the driver of a potentially hazardous situation by means of flashing warning lights in the exterior mirrors. The PDC supports the driver to manoeuvre into tight spaces and reduce stress by informing her/him of the distance from obstacles by means of acoustic or, depending on vehicle, optical signals. The LDW alerts the driver visually and in some cases by means of a haptic signal on the steering wheel, if there is an indication that the vehicle is about to leave the lane unintentionally. The FCW uses a radar sensor to detect situations where the distance to the vehicle in front is critical and helps to reduce the vehicle's stopping distance, alerting the driver in dangerous situations by means of visual and acoustic signals and/or with a warning jolt of the brakes. Common systems that are currently available in the market and physically assist the driver include the Adaptive Cruise Control (ACC) (including also ACC with stop & go function), Park Assist (PA) and Lane Keeping Assist (LKA), which are level 1 systems. The ACC measures the distance and speed relative to vehicles driving ahead and automatically adapts the speed of the vehicle according to driver settings (speed and desired headway). ACC with stop & go function is able to govern braking and acceleration in slow moving traffic, up to a complete stop of the vehicle and then starting again. The PA system assists the driver by automatically steering the car into parallel and bay parking spaces. The LKA system detects the lane markings and if the car starts to drift off lane, takes corrective action up to a point where, if the maximum action it can take is not enough to stay in lane, or the speed falls below 50 km/h, a warning is issued to the driver (e.g. steering wheel vibration). More advanced systems belonging to levels 2, 3 and 4 and currently under development or emerging in the market are Park Assist level 2, Parking Garage Pilot, Traffic Jam Assist, Traffic Jam Chauffeur, Highway Chauffeur and Highway Pilot. Park Assist level 2 accomplishes parking manoeuvres by itself once the process has been initiated by the driver (who can also be located outside the car) via smartphone or key. Parking Garage Pilot is a level 4 system in which the driver does not have to monitor the system and may leave once the system is active. Traffic Jam Assist is a level 2 system which controls the vehicle longitudinally and laterally to follow the traffic flow in low speeds (<30km/h). Traffic Jam Chauffeur is a level 3 system which detects slow driving vehicles in front and handles the vehicle both longitudinally and laterally, up to 60 km/h on motorways and motorway similar roads, without requiring the driver to monitor the system (although prior system activation by the driver is required). Highway Chauffeur is a level 3 system enabling conditional automated driving up to 130 km/h on motorways or motorway similar roads, from entrance to exit, on all lanes, including overtaking. The driver does not have to monitor the system constantly but can be requested to take over control within a specific time, if automation gets to its system limits. Highway Pilot is a level 4 system enabling automated driving up to 130 km/h on motorways or motorway similar roads from entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system, but does not have to monitor it constantly and there are no requests from the system to the driver to take over when the system is in normal operation area (i.e. on the motorway). System definitions are obtained from (ERTRAC, 2015; Gleave et al., 2016). There is no doubt that ADAS are considered to an extent by all the parties involved (industry, policymakers and researchers) a measure of "autonomy" for the vehicles. As stated by Shaout et al. (Shaout et al., 2011), the use of efficient scheduling algorithms and powerful but compact processors has allowed these automotive safety systems to offer powerful benefits to vehicle operators.

According to an article by Intel (Intel, 2014), there are five top requirements enabling ADAS and ultimately self-driving cars: a greater computing power offering the capability of processing approximately 1 GB of data per second, a reliable supply chain with enhanced collaboration among partners, a centralized approach as opposed to the current distributed-computing approach, a small low-power solution based on semiconductors with high processing capabilities and finally, robust security and privacy requirements for data transmissions. All in all, the vehicle's compute architecture needs to move from a decentralized approach with numerous discrete technologies to an approach relying on a more homogeneous system.

The costs of AVs components are already decreasing at a fast pace. For instance, the cost of lidar sensors has decreased from 70,000\$ in 2012 to 250\$ in 2016 and is expected to reach 90\$ with the next generation (Seba, 2016). The same applies to computing devices whose cost is decreasing significantly, while their computational capabilities increase.

Aeberhard et al. (Aeberhard et al., 2015) presented a work supported by BMW on the architecture and algorithms developed while testing AVs on German highways since 2011. Throughout this project, fundamental technologies, such as environment perception, localization, driving strategy and vehicle control, were developed in order to safely operate prototype AVs in real traffic with speeds up to 130 km/h. According to the authors, although there have been major improvements in the last decade, all aspects of the ADS (perception, localization, decision-making and path planning algorithms) need further development to reach the standards of a customer-ready system. The important big step is the industrialization of highly automated driving technology in order to be applied on production vehicles. Finally, the authors state that there is a lot of work to be done, especially in the area of validation/certification and the generation of high resolution digital maps.

Artificial intelligence (AI) based on deep learning architectures, such as deep neural networks (DNNs), is being applied to AV projects (Langenwalter, 2016). Artificial intelligence is an umbrella term for a number of approaches towards creating an artificial system that mimics human thought and reasoning (Gershgorn, 2015). ADS rely heavily on artificial intelligence and deep learning capabilities to make informed decisions and discern its surroundings just like a human driver, i.e. emulating the human brain functions. Deep learning is the process of turning data into decisions of a computer program. The significant difference to algorithm-based systems is that once the basic model is established, the deep learning system learns on its own how to fulfil the intended tasks. Deep learning emulates the way the human brain learns about the world, recognizing patterns and relationships, understanding language and coping with ambiguity.

AVs need to be taught how to drive themselves and especially how to drive in a way that follows human expectations, without creating unnatural or frightening situations for human occupants. Google has acknowledged this need and has admitted to be teaching their cars to mimic these human patterns, favouring wider forward arcs, rather than a series of short movements back and forth (Moseman, 2016).

In (Okumura et al., 2016), the authors pointed out that while computational capacity is becoming less important, the remaining research challenges are in developing perception and decision making algorithms (Ziegler et al., 2014 as cited in Okumura et al., 2016; Bengler et al., 2014 as cited in Okumura et al., 2016) with sufficient performance and reliability in the wide range of environments that can be encountered in real driving. Recently, Machine Learning (ML) advances have taken hold in the automated driving research to provide solutions that outperform traditional approaches while providing a path forward toward developing algorithms for perception and decision making in complex environments. The most common ML algorithms that are being used in AVs are based on object tracking and are aimed at improving the accuracy of pinpointing and distinguishing between objects.

Recent perception research focuses on cameras and lidar, given that the spatial resolution of radar is typically comparably poor (Okumura et al., 2016). Camera systems provide

high-resolution 2D images, whereas high-definition lidars typically give lower-resolution 3D images and information. The success of Google's self-driving car program appears to strongly rely on high-definition lidar as the primary sensor (Chatham et al., 2014 as cited in Okumura et al., 2016; Dolgov et al., 2015 as cited in Okumura et al., 2016).

Global Navigation Satellite System (GNSS) is understood to be a fundamental enabling technology for the automated and connected car. Apart from positioning and navigation, GNSS offer a wide range of applications, including: Precise navigation systems, AVs and assisted driving, C-ITS, Usage-based insurance schemes, Road pricing and congestion charging, Automated eCall distress signals, Intelligent speed alert and adaptation (GSA, 2016). EU GNSS (EGNOS & GALILEO) could be an important technology component to enable both automated and connected vehicles, building upon the fruitful work done for e-Call. In particular, GNSS could significantly assist in improving road management, which will be beneficial both in economic and environmental terms, but also for road safety (GEAR 2030, 2016b). In this area, Galileo, which is expected to be fully deployed by 2020, promises the following advantages: dual frequencies, better reliability and ability to cope with multi-path characteristics in urban environments.

Japan's Quasi-Zenith Satellite System and the EU's Galileo network could be linked by 2018 (Nikkei Asian Review, 2016). The Japanese government and the European Commission recently initiated talks on integrating the systems. Among the companies participating are Mitsubishi Electric, Hitachi Zosen and NTT Data of Japan as well as Thales, a French defence and electronics company.

AVs testing is already possible on EU Member States, following the agreement reached in the UNECE Working Party on Road Traffic Safety (WP.1) stating that there is no need for amendments to the 1949 and 1968 Conventions on Road Traffic for foreseeable types of experiments, i.e. where there is a person who is ready, and able to take control of the experimental vehicle(s) (this person may or may not be inside the vehicle) (UNECE, 2016). When it comes to AV introduction in the EU market, a vehicle certification approach that covers the specificities of their technologies and ensures their safe operation in real driving scenarios is necessary, also in consideration of the fact that these vehicles, after their first registration, may change over time due to system updates or learning algorithms. Since 2009, Google has been driving in full automation mode for more than 2 million miles, mostly in urban environments<sup>(10)</sup>. By the end of 2016, Tesla had accumulated 3 billion miles of driving and 1.3 billion of those were with Autopilot-enabled cars (Lambert, 2016a). Until May 2016, around 100 million miles had been driven with Autopilot on, with regard to the 780 million miles driven in total with Autopilot-equipped cars (Lambert, 2016b). Real driving data is being collected in the different existing AV programmes, either in testing mode or in commercially available systems.

### **3.1.2 Communication technologies**

In-vehicle connectivity is continuously increasing, with approximately 33% of new vehicles in the US and 10% of new vehicles in Europe currently having internet connectivity, and with expectations that in the near future more and more vehicles will have SIM (also because of mandatory e-call from April 2018) or re-programmable cards (Bernhart et al., 2016). New investments should be made in the sector as existing solutions do not seem sufficient enough due to narrow bandwidth, latency and slow transfer of high precision map data. Experts in Europe focus primarily on mobile communication technology with a view to new near-field networks and the 5G mobile network, planned to be launched in 2020. On the other hand, the US is concentrating on a near-field communication technology called Dedicated Short Range Communication (DSRC) that is based on wireless LAN and uses radio-frequency communication. Vehicle communication technologies need to operate in a highly dynamic environment with high speed differences between transmitters and receivers and need to support extremely low latency for safety-critical applications, among

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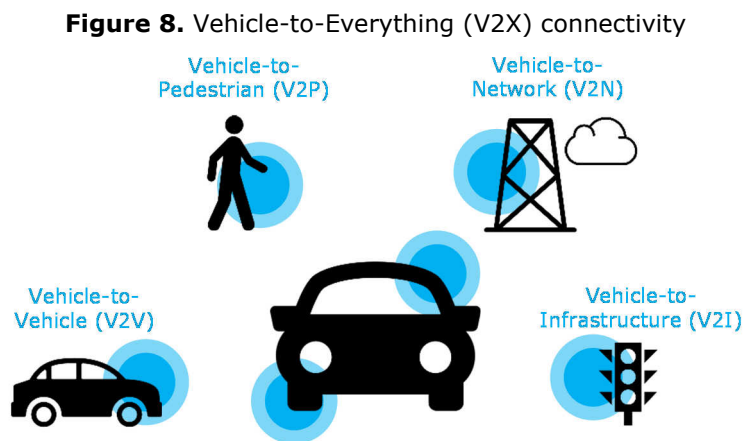
<sup>(10)</sup> See Waymo's site 'On the road' <https://waymo.com/ontheroad/>, last accessed 10 March 2017.



other requirements. Aspects such as security and robustness are critical in vehicle and infrastructure communications.

Communication between vehicles, infrastructure and with other road users is crucial to increase the safety of AVs and their full integration into the overall transport system (European Commission, 2016a). Being complementary to automated driving technologies, it can allow a better perception of the environment. This cooperative aspect is enabled with the so called Vehicle-to-Everything (V2X) connectivity (see Figure 8), which can comprise:

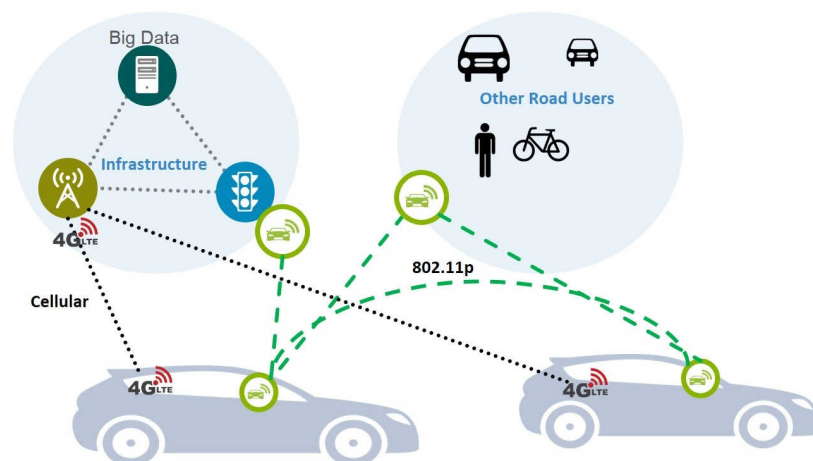
- Vehicle-to-Vehicle (V2V) connectivity
- Vehicle-to-Infrastructure (V2I) connectivity
- Vehicle-to-pedestrian or other vulnerable road users (V2P) connectivity and
- Vehicle-to-network (V2N) connectivity



Source: Own elaborations (adapted from Zaki, 2016) (Icons made by Creaticca Creative Agency, Cursor Creative, Freepik, Madebyoliver and Scott de Jonge from [www.flaticon.com](http://www.flaticon.com)).

Whereas V2V, V2I and V2P rely on short-range ad-hoc connectivity for time-critical safety applications, V2N uses long range commercial mobile networks and bands (as represented in Figure 9). The main communication technologies for V2V, V2I and V2P are the currently available ITS-G5 and the upcoming Cellular V2X (C-V2X, LTE-V2X). They are based on standardised protocols using the 5875-5905 MHz (ITS) band. The main communication technologies for V2N are satellites, 3G, 4G, LTE and the oncoming 5G. Mobile network or subscription is only required in the latter case, i.e. V2N.

**Figure 9.** Cellular and IEEE 802.11p for C-ITS



Source: Filippi et al., 2016.

As acknowledged in the C-ITS communication (European Commission, 2016a), users are not concerned about which communication technology is used to transmit C-ITS messages, but will more and more expect to receive every traffic and safety information seamlessly across Europe. A hybrid communication approach (i.e. combining complementary communication technologies) is seen as the only possibility to achieve this. The C-ITS communication indicates that the most promising hybrid communication mix at present is a combination of ETSI ITS-G5 for time-critical safety-related C-ITS messages and existing cellular networks for wide geographical coverage and access to large user groups. The communication technology to use will thus depend on the specific use case where automation is implemented.

Thus, a variety of wireless communications technologies are available depending on the specific application (e.g. whether the application is safety-related or not), as they require different distance ranges, speeds and reliability (e.g. safety-critical applications require high reliability but do not require high bandwidth, whereas internet-streamed radio requires high bandwidth but not high reliability).

Some wireless communication technologies which are used within the vehicle are the following:

- Very short range: Bluetooth, Near Field Communication (NFC) and Radio Frequency Identification (RFID) (e.g. to connect a smartphone to the vehicle display)
- Short range: Dedicated Short Range Communication (DSRC) based on the IEEE 802.11p standard (ETSI-G5) (e.g. suitable for safety-critical applications in the 300–500m range)
- Long range: Cellular (e.g. used for communication with Traffic Control Centre), Wi-Fi and GPS

DSRC and cellular form the most promising communication mix, as previously quoted. The main advantages of DSRC are short latency, limited interference, low sensitivity to weather conditions and the fact that it does not require subscription to a mobile operator's network. With regard to cellular technologies, there is almost a 100% mobile network coverage in most developed countries and a significant part of the population equipped with a mobile phone with data transfer capabilities. They offer communication to any user equipped with a mobile phone (not just to vehicles). Cellular communications are rapidly evolving from second generation (2G) networks offering download speeds of 140 kbps, to third generation (3G) with speeds of up to 14 mbps, and fourth generation (4G) Long Term Evolution (LTE) offering 173 mbps.

On September 2016, BMW, Audi and Daimler teamed up with telecommunications companies Ericsson, Huawei, Intel, Nokia and Qualcomm Incorporated to create the 5G Automotive Association that will develop, test and promote communications solutions, support standardization and accelerate commercial availability and global market penetration (Nica, 2016). Additional partners have joined the association since then (e.g. Vodafone Group, Deutsche Telekom, Valeo, SK Telecom, LG, Ford, Denso) <sup>(11)</sup>. Connected automated driving is part of their focus. Next generation mobile networks are expected to handle much greater volumes of data, connect many more devices, significantly reduce latency and bring new levels of reliability. For example, 5G can better support mission-critical communications for safer driving and will further support enhanced V2X communications and connected mobility solutions. The companies will jointly work on use cases, technical requirements (such as wireless connectivity, security, privacy, authentication and distributed cloud architectures), implementation strategies, standardization, regulation, certification and approval processes. In addition, the 5G-ConnectedMobility consortium <sup>(12)</sup> comprising Ericsson, BMW, Deutsche Telekom, Telefónica, Vodafone, the Technical University of Dresden (TUD), the German Federal Highway Research Institute (BAST), and the German Federal Regulatory Agency (BNetzA)

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<sup>(11)</sup> 5GAA website, <http://www.5gaa.org/>.

<sup>(12)</sup> 5G-Connected Mobility website, <https://eth.org.hu/5G-ConnectedMobility/en>.



is aiming to build a Digital Test Field Motorway on a 30-kilometre road stretch in Germany, between the junctions of Nuremberg-Feucht and Greding, to accelerate 5G R&D in Germany and in Europe. Research will focus on applications for V2V and V2I communications, as well as new traffic information and management for AVs.

Given that typically the development cycle of a vehicle is around 5 years (while it is around 2 years for a smartphone and just a few months for an app), a vehicle's integrated connectivity system will rapidly have obsolete hardware and almost certainly obsolete software when it enters the market (FIA, 2016). It is then normally sold for 5-6 years without major redesign and the average life expectancy of a car on EU roads is in the range of 12 years. Remotely updating the vehicle software is an option that is already being exploited (e.g. Tesla is adding new features and functionalities through regular Over-The-Air (OTA) software updates).

As regards communication technologies and frequencies, the C-ITS communication (European Commission, 2016a) has indicated the following specific actions:

- *“Road authorities, service providers, vehicle and radio equipment manufacturers and other industrial players should adopt a strategy for hybrid communication in procurement and serial production in order to support the full Day 1 C-ITS services list.*
- *Telecom operators that support C-ITS services should appropriately manage network load for road safety related C-ITS services.*
- *The Commission will maintain the designation of spectrum used by ETSI ITS-G5 for safety-related ITS services and support measures to protect this frequency band from harmful interference, both at the European and international level (UN International Telecommunication Union and European Conference of Postal and Telecommunications Administrations).*
- *C-ITS deployment initiatives should implement the relevant mitigation techniques for co-existence according to ETSI standards and procedures.”*

### **3.1.3 Telematics architecture**

Telematics, a composition of telecommunications and informatics (Rencken, 2016), encompasses the computer and electronics in a car. Electronic Control Units (ECUs) are micro-processing modules which form the core of the vehicle electronics system (Lawson et al., 2015). Each of them controls a specific set of functions (e.g. engine, transmission, automatic braking, air bags, air conditioning) by gathering data from sensors and sending instructions to actuators. They communicate with each other using a standard protocol (commonly the Controller Area Network CAN standard). Among the 70 ECUs which are part of modern vehicles today, there is the Telematics Control Unit (TCU), which provides the platform for the delivery of telematics services.

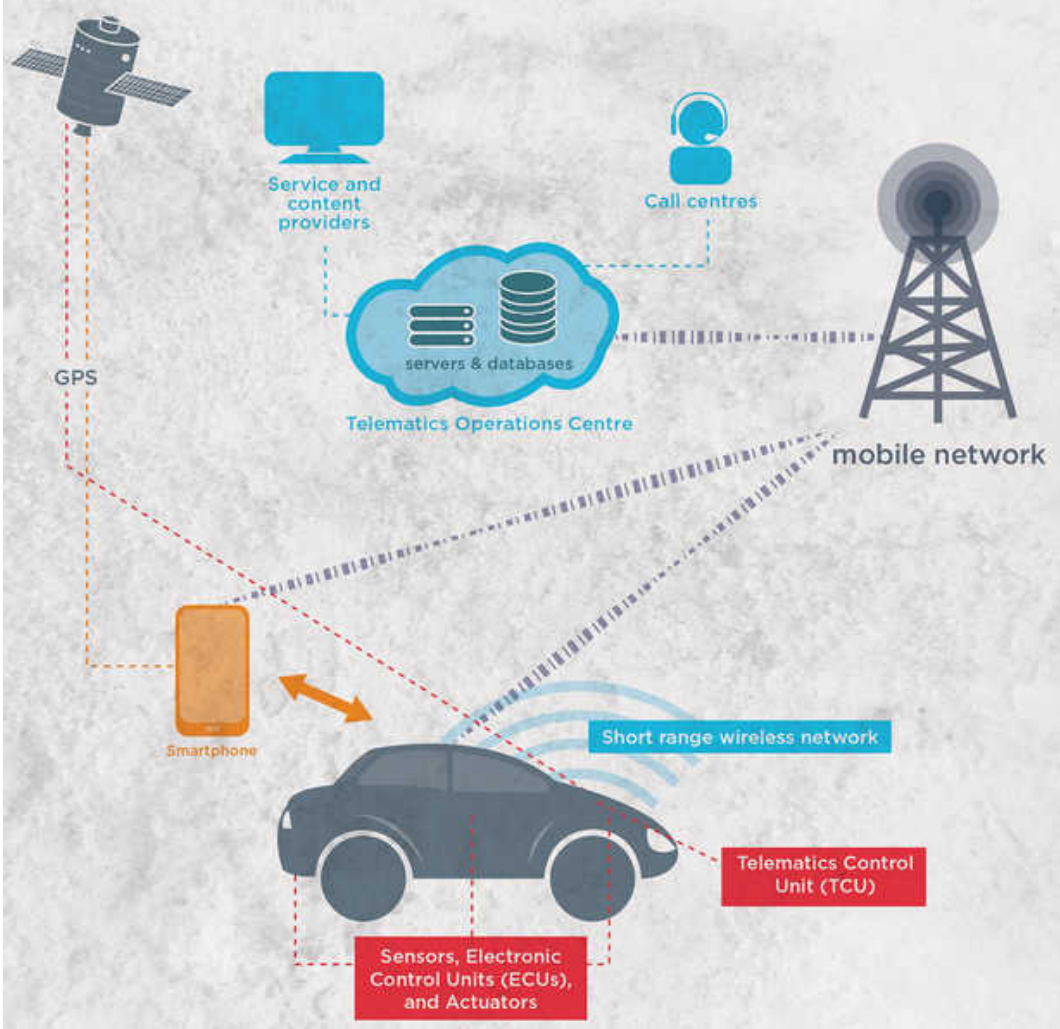
Typically, the following key components can be found in a vehicle telematics system (see Figure 10):

- An in-vehicle TCU connected to the vehicle CAN bus.
- A GPS receiver that is attached to or forms part of the TCU.
- A Telematics Operations Centre, that processes data from the TCU, combines it with other gathered data and delivers telematics services.
- A wireless communications system over which data and voice communications are exchanged between the TCU and the Telematics Operations Centre.
- Service and content providers who provide information, entertainment and other services (e.g. traffic information, music) to the Telematics Operations Centre.
- A call centre with customer service representatives who can communicate with vehicle occupants.

Today’s vehicles already use cellular-based telematics for emergency assistance, vehicle monitoring, and the provision of entertainment and navigation services (Chan, 2011). AVs will need to receive remote updates for their maps and their algorithms—updates that will likely depend on the real-world data that these vehicles collect and transmit (Smith, 2014).

A Vehicular Ad Hoc Network (VANET) permits moving vehicles in a certain environment to communicate with each other. Its main objective is to help a group of vehicles to set up and maintain a communication network among them without using any central base station or any controller (Rehman et al. 2013). They are a particular class derived from Mobile Ad hoc Networks (MANETs) and can enhance the security and efficiency of transport systems by providing information about weather conditions and road conditions such as road accidents, traffic congestion, etc. VANETs are characterized by quickly changing network topologies, hostile propagation environment and high variable vehicle speed (Hartenstein and Laberteaux, 2010).

**Figure 10.** OEM Telematics architecture



Source: Lawson et al., 2015 (Creative Commons Attribution NonCommercial 2.5 Canada license, CC BY-NC 2.5 CA, <https://creativecommons.org/licenses/by-nc/2.5/ca/>).

Message propagation occurs through V2V and V2I links. V2V links can involve any vehicle nearby in order to build an end-to-end path toward a final point. One of the problems in V2V communication is that the vehicle network environment is dynamic and complex and sources of information can be heterogeneous. Bou Farah et al. (Bou Farah et al., 2016) focused on the management of imperfect information exchanged between vehicles concerning events on the road. V2I links assume the presence of fixed road-side units

everywhere in the infrastructure. According to Campolo et al. (Campolo et al., 2015), a refinement of the existing technology standards in VANETs is expected along with a new release to support more advanced and complex use cases in a scenario with increased market penetration of equipped vehicles and road-side infrastructure coverage. Security and privacy, two very important issues in VANETs, are considered critical in the development of robust VANET applications. Several network security issues resemble those of traditional wireless networks. According to Cunha et al. (Cunha et al., 2016), security challenges in VANETs are intrinsic and unique due to the size of the network, frequent topology changes, high mobility, and the different classes of applications and services, with conflicting requirements that will be offered to such networks. Integrity of the exchanged information as well as availability of the system are two main challenges regarding future generation VANETs.

Automation of several vehicle functionalities is needed to realise the AV concept whereas the communication between vehicle's functionalities, nearby vehicles, infrastructure and the central controller of the transport system is needed to make the C-ART network real. The latter concept forms part of the Internet of Vehicles (IoV), a term which derives from the Internet of Things (IoT) convergence with the mobile Internet. There are several papers in the literature discussing the IoV concept. According to Ala Al-Fuqaha et al. (Al-Fuqaha et al., 2015), the IoT is enabled by the latest developments in RFID, smart sensors, communication technologies and Internet protocols. The basic premise is to have smart sensors collaborate directly without human involvement to deliver a new class of applications. The current revolution in Internet, mobile, and Machine-to-Machine (M2M) technologies can be seen as the first phase of the IoT. In the coming years, the IoT is expected to bridge diverse technologies to enable new applications by connecting physical objects together in support of intelligent decision making. As Gerla et al. notes (Gerla et al., 2014), like other important instantiations of the IoT (e.g. the smart building), the IoV will have communications, storage, intelligence and learning capabilities to anticipate the customers' intentions. The concept that will help transition to the IoV is the Vehicular Cloud, the equivalent of Internet cloud for vehicles, providing all the services required by AVs. Zhang and Xi (Zhang and Xi, 2016) focus on the potential of IoV where vehicles can easily exchange information with other vehicles and infrastructures, and therefore can greatly improve vehicles safety, promote green information consumption and have a profound impact on many industries. Regarding security and privacy, similarly to VANETs, Sun et al. (Sun et al., 2015) highlights the fact that IoV systems, due to their characteristics of dynamic topological structures, huge network scale, non-uniform distribution of nodes, and mobile limitation, face various types of attacks, such as authentication and identification attacks, availability attacks, confidentiality attacks, routing attacks, data authenticity attacks, etc., which result in several challenging requirements in security and privacy. Future trends in IoV include the reduction of defects of Intrusion Detection Systems, privacy protection in routing, risk analysis and management, trust and verification of data centre, privacy and security protection on Mobile Cloud Computing and dealing with Big Data.

### 3.1.4 Preliminary technology requirements for C-ART

Building on previous subsections, the following table provides a list of preliminary technology requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration (some of them are equally relevant for the data section).

**Box 1.** Summary of technology aspects of relevance for C-ART

**The C-ART system would initially require:**

- Highly automated driving technologies (starting at level 3 but preferably level 4 and level 5 automation systems).
- The AV algorithms would need to be known by the C-ART system, at least up to a certain degree. This highlights the need for data sharing among relevant actors.

- V2X connectivity (mostly V2I) will be essential in C-ART as AVs need to communicate with the RTMS and could benefit from further communication possibilities.

**Key remaining open questions are:**

- Which data are required by the AVs for a fast, safe, reliable and efficient mobility? (Devices needed? Synergies with enabling technologies like 5G or Galileo? Data requirements? Which data to be provided and maintained by road transport authorities? Which types of data will need management? Do we need to store all data? Data privacy concerns? Security concerns?)
- How to manage huge amounts of data? (Transmission problems? Latency issues? Do we consider the same order of volumes for individual AV management as for C-ART management or are these two different approaches? Which data can be shared?)
- AVs connected to a central controller? How should it optimize the transport system? (Who should govern it? Prioritization / Optimization criteria? E.g. travel time, costs, energy use, air pollution, accident risk, etc. At which level? E.g, urban, rural, national. Which are related challenges, also computationally?)
- Would AVs need to undergo an examination to obtain a driving license or can this be covered through the type approval procedure? (Testing?)
- Operational issues? (e.g. roadway types, geographical location, speed, range, lighting conditions (day and/or night), weather conditions, cross-border driving...?)
- What is the view of the industry? Is AV coordination feasible with the existing technologies? What kind of technologies are proposed?

### **3.2 Infrastructure**

Although AVs can in principle operate by sensing the infrastructure and traffic just through in-vehicle sensors and cameras, the role that road infrastructure can play in actively assisting ADS has been vastly recognised. Current road infrastructure has been built to accommodate for the circulation of conventional, i.e. human-driven, vehicles and would thus require some adaptations to accommodate this new kind of vehicles. Making substantial changes in the current physical infrastructure would be costly and there is still a lack of information about which specific requirements would apply. Thus in the short and medium terms, no major physical changes are expected to take place in current roads. However, the right management and maintenance of roads is of paramount importance for the safe and reliable operation of AVs. In this context, Directive 2008/96/EC on infrastructure safety management may need to be modified to include the infrastructure requirements of AVs (GEAR 2030, 2016b). Then bigger infrastructure changes could be expected in the long term, once fully automated driving is a reality and allows for new planning perspectives (e.g. urban planning). In addition to the physical infrastructure (e.g. road signs, road markings, communication infrastructure), the digital infrastructure (e.g. map data, traffic dynamic data) is also of relevance in the context of AVs and especially C-ART. V2I communication technologies will play a relevant role in transmitting important data from and to the infrastructure in order to support the safe and efficient operation of vehicles (not only AVs). For instance, applications such as FCW or LCA can be based on V2I communications, where different sensors and Road Side Units (RSU) in the infrastructure communicate relevant information to surrounding vehicles. The following subsections describe the main physical and digital infrastructure challenges.

#### **3.2.1 Physical infrastructure**

With physical infrastructure we mean the roads, road signs, road markings, communication infrastructure, etc. that form part of the physical world where vehicles operate. Many partial or fully automated driving technologies rely on road infrastructure being readable (Townsend, 2016). Systems like LKA, LDW and Traffic Sign Recognition (TSR) impose certain requirements from road markings and traffic signs (King, 2013). However, road

infrastructure requirements and consequences of higher automation levels are not clear (ERTRAC, 2015). Standards and harmonisation might be proposed in this context but given the restrained road maintenance budgets in many EU member states, the dependency and impact on roads management and maintenance need to be reduced to a minimum (ERTRAC, 2015). Usually, infrastructure improvements require high investments but adaptations such as the provision of a simplified and logical environment that can support the vehicle to avoid situations of many stops (cross sections, pedestrians/bicycle crossings, etc.) are also possible (ERTRAC, 2015). Also, there is the possibility of limiting AVs to some dedicated infrastructure, as could likely be the case in urban areas. In highways, there could be the need to include lay-bys for drivers' reengagement in the driving task before leaving the highway (Townsend, 2016). Nonetheless, different infrastructure systems that could support automated driving are already in place, such as video monitoring systems, video/cameras for traffic monitoring and journey time estimation, speed cameras, traffic detection (infrared, laser, microwave), communication for toll collection (Zhang, 2013).

Specifically, road markings must be clearly visible to the driver, both during daytime and night-time conditions, and in all weathers (King, 2013). The effectiveness of road markings depends on their luminance (meaning how well the marking stands out on the road) and their retro-reflectivity (the amount of light reflected back to the driver to make the marking visible). Worn out road markings or obsolete road markings which have not been completely blacked out may interfere with an adequate performance of the automated system. There are European standards that stipulate different levels of retro-reflectivity in varying weather conditions, e.g. European Norm (EN) 1436: Road Marking performance for road-users.

Similarly, traffic signs must be clearly visible and must comply with the principle of retro-reflectivity, in this case through European standard EN 12899. Different factors can affect the adequate performance of the ADS, e.g. vandalism on the traffic sign, obscured sign (as a result of e.g. other signs, summer foliage, etc.), wrong position, cross border differences. Variable Message Signs are often difficult to read with camera sensors because they are using technologies and control systems designed for the human eye (King, 2013).

In a publication by Zhang (Zhang, 2013) a review of the main infrastructure modifications needed for automated driving was made. From this review, the following main studies are highlighted. Tsao (Tsao, 1995 as cited in Zhang 2013) presented a gradual infrastructure modification based on growing demand and including: check-in (inspection) facilities at entry points, installation of lane markers, traffic monitoring devices, roadside controllers, and roadside-vehicle communication devices. Similarly, Al-Ayat and Hall (Al-Ayat and Hall, 1994 as cited in Zhang, 2013) recommended a set of guidelines for infrastructure expansion for automated driving, in which there is the idea that functionality provided at each step is useful by itself, has a high likelihood of acceptance by users and does not require full deployment of subsequent steps. Tsugawa et al. (Tsugawa et al., 2000 as cited in Zhang, 2013) proposed an architecture for cooperative driving of AVs, comprising a vehicle control layer, a vehicle management layer and a traffic control layer, the latter with a physical part that includes infrastructure-based ITS equipment such as sign boards, traffic signals and road-vehicle communications. In the CityMobil project, specially designed eLanes were proposed which are certified for automated driving in a mixed traffic environment (Toffetti et al., 2009 as cited in Zhang 2013).

### **3.2.2 Digital infrastructure**

Digital infrastructure includes static and dynamic digital representations of the physical world with which the AV will interact (OECD/ITF, 2015a). For instance, digital maps, dynamic information from vehicle and infrastructure sensors (e.g. traffic data), advanced communication and positioning technologies.

AVs need reliable dynamic map data to operate in real driving scenarios. Map information delivered in real time can extend the perception range of AVs. A so called "electronic horizon" provides the possibility to adapt driving behaviour to the predictable road curves and slopes for comfort or fuel saving (Gicquel, 2015). This electronic horizon is essential

in AVs and needs to comply with high precision and update frequency requirements. Also, there is the need for standardising data formats so that information can be exchanged among different actors and be used for the provision of services.

While some people argue that a fully automated vehicle should be able to rely on its own sensors and perception capabilities (Pilli-Sihvola et al., 2015 as cited in Townsend, 2016), it has to be acknowledged that digital infrastructure may improve the automated systems performance by providing additional information about road users, traffic and infrastructure (e.g. upcoming traffic congestion, road accident) so that the automated system can make better informed decisions. This requires connectivity and thus digital infrastructure enabling V2V and V2I communication. A fully automated vehicle will thus require a more demanding and more accurate set of data on the traffic environment (Townsend, 2016). Among the issues to be addressed there are the following: sourcing, processing, quality control, information transmission, security, data protection. This aspect is closely linked to the data topic which is discussed in section 3.4.

### 3.2.3 Levels of Infrastructure automation

**Table 4.** Levels of Infrastructure automation

System Concept	Local Position Keeping	Lane Changing	Obstruction on Roadway	Flow Control
Infrastructure supported: fully automated vehicles operate on dedicated lanes, using global information and two-way communication with smart infrastructure to support vehicle decision making.	Vehicle sensors, communications from other vehicles for lane changes or platoons with guidelines from infrastructure.	Cooperative negotiation among vehicles.	Infrastructure or vehicle sends communication to vehicles; vehicles coordinate.	Infrastructure monitors traffic, formulates responses, sends parameters to local groups of vehicles.
Infrastructure managed: automated roadside system provides inter-vehicle coordination during entry, exit, merging, and emergencies.	Vehicle sensors, communications from other vehicles, and infrastructure as needed.	Vehicle requests lane change; infrastructure responds with commands for surrounding vehicles.	Infrastructure sends commands to vehicles based on infrastructure or vehicle detection or vehicle actions.	Infrastructure monitors individual vehicles, commands vehicles as needed, including entry and exit.
Infrastructure controlled: same as above, but infrastructure takes full control in all driving situations.	Infrastructure senses vehicle positions and sends commands to control throttle, braking, and steering.	Infrastructure determines need for lane change from origin-destination data, controls all necessary vehicles.	Infrastructure sends commands to vehicles based on infrastructure or vehicle detection or vehicle actions.	Infrastructure monitors individual vehicles, performs optimizing strategy through control of individual vehicles.

Source: Cheon, 2003 (as cited in Zhang, 2013).

From the perspective of the road infrastructure, three different levels of automation were proposed by Cheon (Cheon, 2003 as cited in Zhang, 2013): infrastructure supported, infrastructure managed and infrastructure controlled (see Table 4). Respectively, they range from a mere support from the infrastructure in vehicle decision making to the coordination of vehicles in entry, exit, merging and emergencies up to the full control of all driving situations by the infrastructure.



### 3.2.4 Infrastructure requirements according to vehicle automation levels

On the basis of NHTSA levels of automation, Zhang (Zhang, 2013) gathered a set of roadway/infrastructure requirements that would apply to each level of vehicle automation (see Table 5).

**Table 5.** Infrastructure requirements according to NHTSA levels of automation

Level of Automation	Narrative Definition	Potential Roadway/ Infrastructure Requirement
<b>Level Zero – No Automation</b>	Driver has complete control over vehicle; no input from vehicle towards driving.	<ul style="list-style-type: none"> <li>No requirement.</li> </ul>
<b>Level One – Function-Specific Automation</b>	One or more specific functions are automated. If multiple functions are automated, they operate independently from each other. Driver still has overall control.	<ul style="list-style-type: none"> <li>Speed limit beacons for controlling speed and regulating traffic flow through construction sites or inclement weather.</li> <li>Safety messages from roadway infrastructure for enhanced traffic signal operations.</li> <li>Warnings to drivers of unexpected queues.</li> </ul>
<b>Level Two – Combined-Function Automation</b>	More than one primary function automated, giving driver freedom to disengage from these functions. Driver still has overall control.	<ul style="list-style-type: none"> <li>Speed limit beacons for controlling speed and regulating traffic flow through construction sites or inclement weather.</li> <li>Safety messages from roadway infrastructure for enhanced traffic signal operations.</li> </ul>
<b>Level Three – Limited Self-Driving Automation</b>	Driver can cede control of all primary functions of vehicle in a particular traffic environment. Once environment changes, driver required to take back control.	<ul style="list-style-type: none"> <li>Speed limit beacons for controlling speed and regulating traffic flow through construction sites or inclement weather.</li> <li>Safety messages from roadway infrastructure for enhanced traffic signal operations.</li> <li>Warnings to drivers of unexpected queues.</li> <li>Magnetic nails/reflective striping for lane keeping.</li> <li>Infrastructure-assisted merging and lane changing, aided by Road Side Units (RSUs).</li> <li>Possible investments in dedicated lanes mooted.</li> </ul>
<b>Level Four – Full Self-Driving Automation</b>	Vehicle capable of performing all safety-critical driving functions and monitoring roadway for entire trip. Driver needs to provide destination/ navigation input, but is not expected to be available for control at any time during trip.	<ul style="list-style-type: none"> <li>Speed limit beacons for controlling speed and regulating traffic flow through construction sites or inclement weather.</li> <li>Safety messages from roadway infrastructure for enhanced traffic signal operations.</li> <li>Warnings to drivers of unexpected queues.</li> <li>Magnetic nails/reflective striping for lane keeping.</li> <li>Infrastructure-assisted merging and lane changing, aided by RSUs.</li> <li>Investments in full swing for dedicated lanes to enable platooning of vehicles.</li> </ul>

Source: Zhang, 2013.

### 3.2.5 Preliminary infrastructure requirements for C-ART

Building on previous subsections, the following table provides a list of preliminary infrastructure requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration (some of them are equally relevant for the data section).

**Box 1.** Summary of infrastructure aspects of relevance for C-ART

**The C-ART system would initially require:**

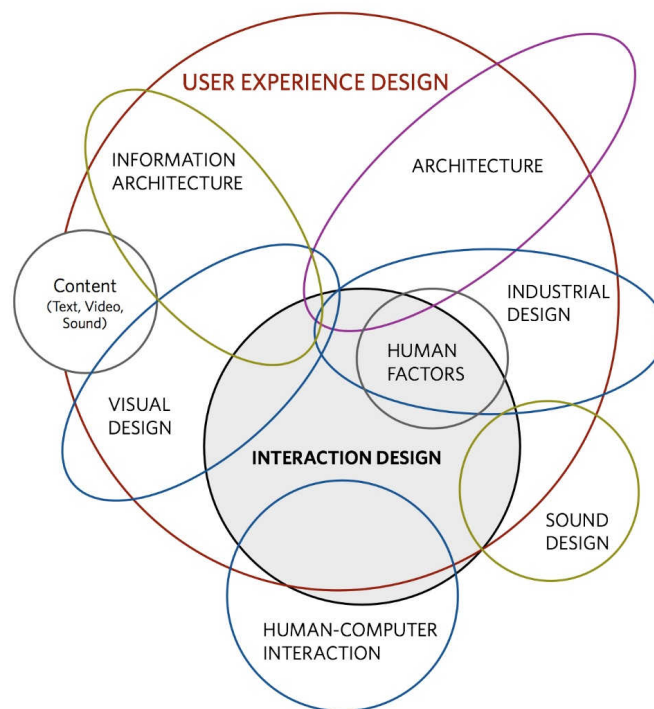
- Road infrastructure would need to be equipped with RSUs to communicate with AVs and with the RTMS.
- Road infrastructure would need to be equipped with traffic monitoring devices in order to monitor the driving situation.
- Road markings and traffic signs must be clearly visible at all times (although traffic signs will also be part of the map data).
- Digital infrastructure is of paramount importance for C-ART and is required to comply with high accuracy, frequent update rates, security, data protection, etc. Having a standardised data format is essential.

**Key remaining open questions are:**

- What are the specific data requirements for C-ART?
- Could the infrastructure adopt a more active role in the management of the road transport system? (i.e. not just monitoring and communicating but actually controlling traffic)

### 3.3 Human factors

**Figure 11.** UX disciplines



Source: Saffer, 2008.

Human factors can be defined as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them



compatible with the needs, abilities and limitations of people" <sup>(13)</sup>. The study of human factors effects on driver behaviour has been a subject of research for many decades, studying aspects such as e.g. distraction, workload, fatigue, alcohol, etc. Even if AVs are expected to cope with many of these so called human factors, intermediate levels of automation (e.g. levels 2, 3) will still require the presence of a driver in the car taking active control of the vehicle in many situations and will thus require to consider human factors implications. With higher levels of automation (i.e. levels 4 and 5), the driver will take the role of a passenger and human factors requirements will be softened but still user-related aspects will be of relevance. Specifically, User Experience (UX) is a term encompassing every aspect of the user's interaction with a product, service, or company that make up the user's perceptions of the whole <sup>(14)</sup>. It includes the utilitarian aspects as well as the more emotional aspects of the interaction with a given system. A review of the most important human factors challenges for AVs is provided in the next subsection, followed by a review of the specific aspects that relate to the interface between the driver and the vehicle (the Human-Machine Interface, HMI) and those relating to user acceptance.

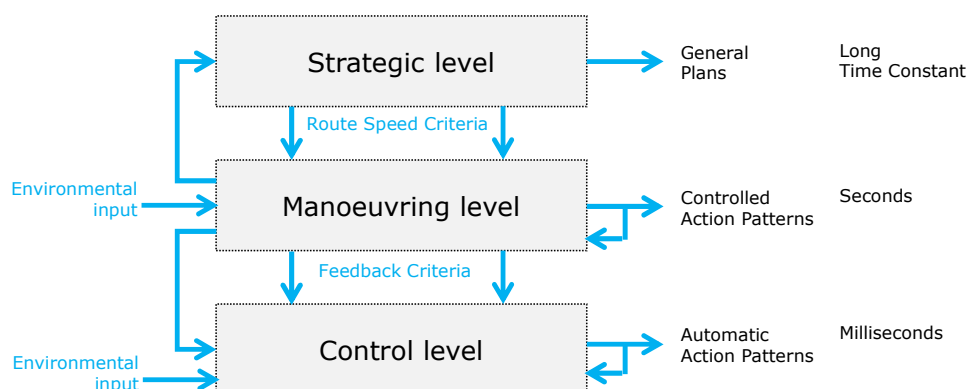
### 3.3.1 Human factors challenges involved in automated driving

Advanced automation can fundamentally change the driving task and the role of the driver in the transport system. The driving task is "a highly complex activity involving the coordinated execution of multiple and assorted tasks or sub-tasks in a more or less simultaneous way, whose performance is demanded appropriate, effective and safe in a dynamic environment with constant and continuous changes (i.e., the road traffic environment)" (Saad, 2002). The road traffic environment is defined by a process of interdependent, continuous and dynamic exchanges between its various components and actors.

The driving task can be divided into three types of activities which are necessary to operate a vehicle (Michon, 1985; see Figure 12):

- Strategic behaviour, which refers to the travel planning (e.g., to define driving goals and to choose the route or mode), considering available options, costs and risks involved.
- Tactical (or manoeuvring) behaviour, e.g. speed selection, lane selection, object and event response selection, and manoeuvre planning.
- Operational (or control) behaviour, e.g. longitudinal and lateral control as well as object and event detection and classification.

**Figure 12.** The hierarchical structure of the road user task



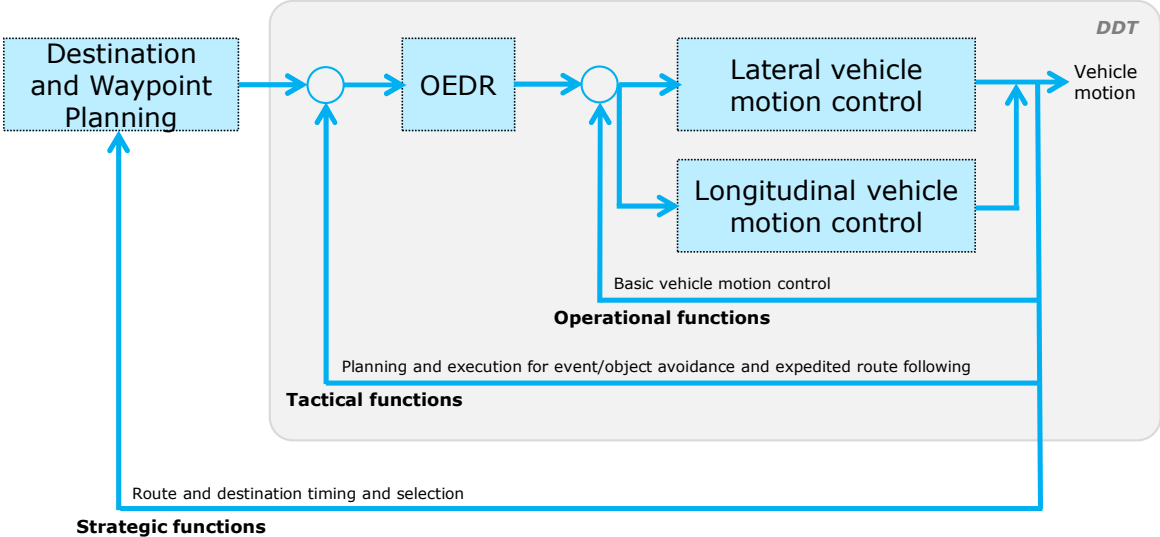
Source: Own elaborations (adapted from Michon, 1985).

<sup>(13)</sup> Definition developed by the International Ergonomics Association and adopted by the Human Factors and Ergonomics Society, <https://www.hfes.org/Web/EducationalResources/HFEdefinitionsmain.html>.

<sup>(14)</sup> Usability Body of Knowledge Glossary, <http://www.usabilitybok.org/glossary/19#letteru>.

As outlined by Christensen et al. (Christensen et al., 2015), the operational behaviours of longitudinal and lateral control refer to those driver actions performed using closed-loop control of vehicle speed (using the accelerator and/or brake pedals) and position in the lane (using the steering wheel). OEDR is defined as the perception of any circumstance relevant to the immediate driving task and the appropriate reaction to such circumstance (Christensen et al., 2015). Within the overall task of driving, the operational and tactical behaviours relate directly to the dynamic aspects of driving and are thus grouped into what is referred to as the dynamic driving task, or DDT (SAE International, 2016; see Figure 13).

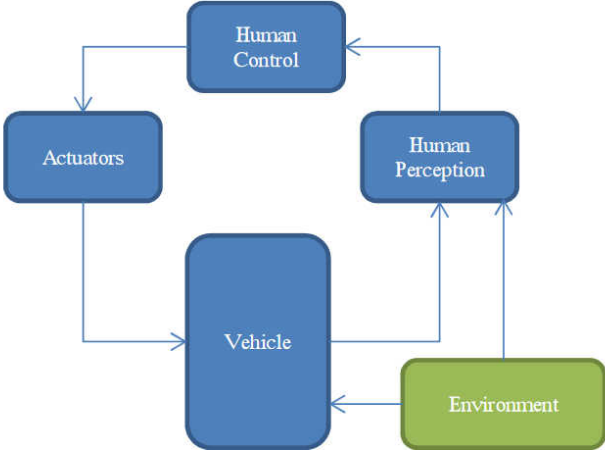
**Figure 13.** Schematic view of the driving task showing the portion of the DDT



Source: Own elaborations (adapted from SAE International, 2016).

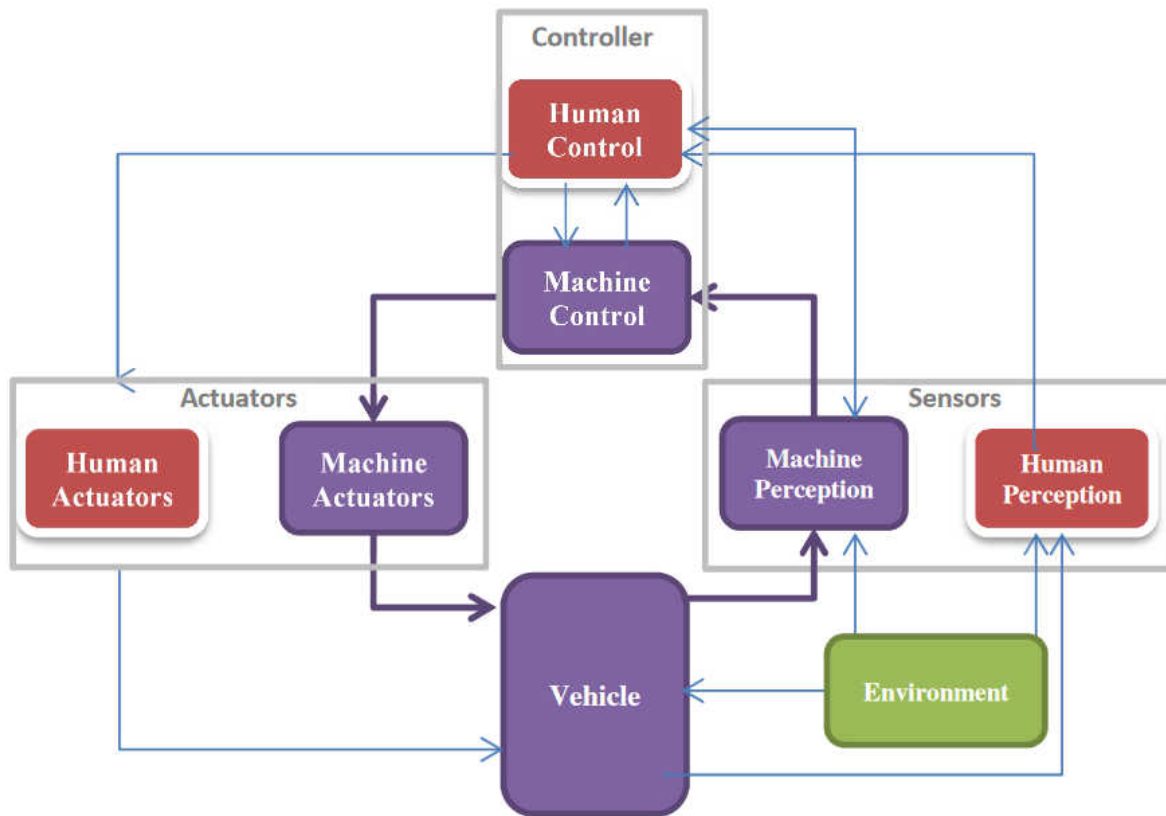
Operational and tactical tasks would be transferred to the vehicle in advanced automated systems classified as levels 3, 4 and 5. In this context, automation, by taking away the easy parts of a task, can make remaining tasks for the driver more difficult (Bainbridge, 1987 as cited in Dekker and Woods, 2002). This is because automation may take the driver out of the loop by either decreasing driver workload (underload) or increasing it (overload), by an excess of trust on the system, by deteriorating situational awareness or by inducing changes in driver behaviour which are unintended by system designers. See Figure 14 and Figure 15.

**Figure 14.** Human operation of a traditional vehicle – the DDT



Source: Christensen et al., 2015.

**Figure 15.** The introduction of machine automation to the DDT



Source: Christensen et al., 2015.

A recent communication of the Association for Computing Machinery (ACM) (Casner et al., 2016) covers the human factors challenges involved in partially automated driving, which are according to the authors underestimated today. The role of the driver in partially automated vehicles is not fully clear, as drivers are sometimes placed in the role of a driver while sometimes they occupy the role of a passenger. The article draws on previous researches on the safety effects of automation in aviation, acknowledging that incomplete and imperfect automation will create difficult challenges as those already experienced in the airline cockpit in the past decades. Paradoxically, increasing automation may lead to declining the level of awareness (Casner et al., 2014 as cited in Casner et al., 2016) which will pose significant safety challenges when transitioning from automated to manual driving in the event of an unexpected circumstance. The experience in aviation strongly supports this idea. A new kind of accidents may emerge as a consequence. The Human-Machine Interface (HMI) plays a significant role in automated systems by making clear the state of the automation, what is being done and what is planned to be done next. At the same time addressing situations in which the driver attempts to engage an automation function that is not ready, avoiding potential surprises resulting from wrong assumptions. HMI strategies may consider periodically asking drivers to assume manual control of the vehicle in an effort to maintain driving skill, wakefulness or attentiveness. Also, in this context, the automated system may constantly monitor the driver status during the drive to ensure that the driver is able to resume the control of the vehicle at a given moment. A summary of the main reported human factors problems for each NHTSA level of autonomy is presented in Table 6. NHTSA level 4 (high/full automation, i.e. SAE levels 4/5) is left out of this analysis as drivers are not anymore occupying the drivers' role but feature as passengers of the AV.

**Table 6.** Summary of reported human factors problems for each level of autonomy

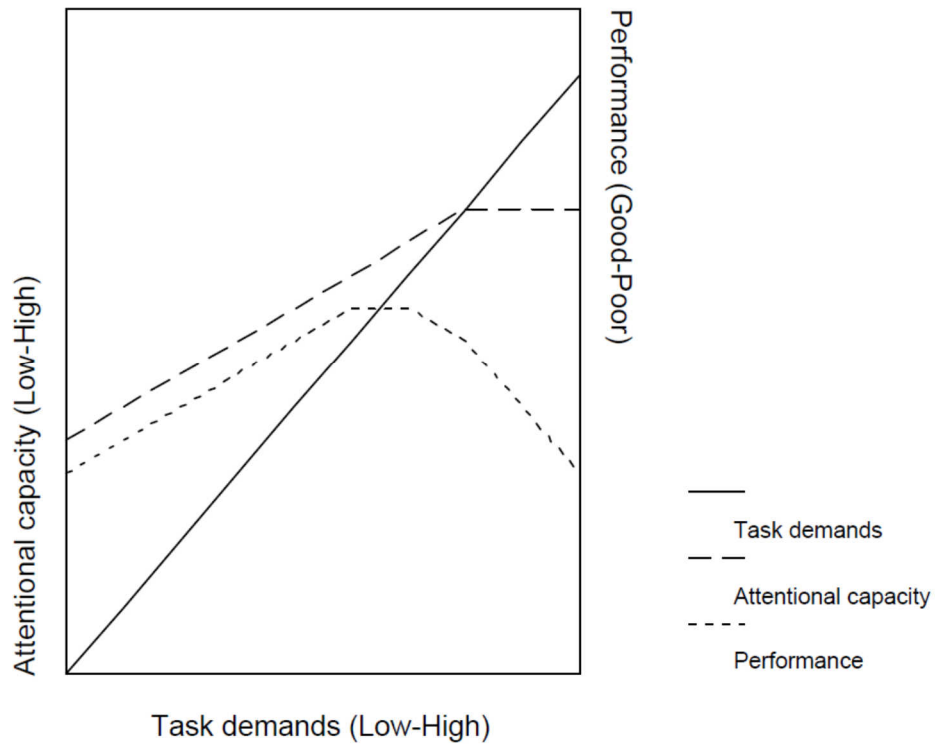
LEVEL OF AUTOMATION (NHTSA)	HUMAN FACTORS PROBLEMS
<p>0 (e.g. navigation systems, driver warning systems)</p>	<p>Inattention: distraction during secondary visual-manual tasks (like operating the navigation system or a personal electronics device), cognitive distraction (conversation or mind wandering) or inattention resulting from extended periods of time where the system performs well, which makes drivers feel they no longer need to pay close attention to the system. This last point relates to problems focusing attention when there is little or nothing to attend to, thus reducing active involvement and simply obeying the navigation instructions.</p> <p>Trust: automation systems earn users trust following periods of impeccable performance, even reaching the point where they believe that the automation knows best (Hoff and Bashir, 2014 as cited in Casner et al., 2016).</p> <p>Quality of feedback: when presenting limited information about context and surroundings, it is easy for drivers to miss important clues when things go wrong.</p> <p>Skill atrophy: cognitive skills deteriorate when not practiced regularly.</p> <p>Complacency: unintendedly, some drivers may substitute the primary task of paying attention with the secondary task of listening for alerts and alarms (i.e. relying on alert systems to call when troubles appear).</p> <p>Nuisance: failing to alert or alerting too much is counterproductive, also alerting in situations that users do not find alarming (Breznitz, 1984 as cited in Casner et al., 2016).</p> <p>Alert times: the effectiveness of alerts falls off when alert times are short, as driving requires a fast response.</p>
<p>1 (e.g. adaptive cruise control)</p>	<p>Vigilance: taking drivers out of the active control makes it difficult to get them back in when it is necessary, as previous studies have reported reduced vigilance, increased drowsiness and longer reaction times to unexpected events when relieving drivers of even one aspect of the driving task (Dufour, 2014 as cited in Casner et al., 2016).</p>
<p>2 (e.g. traffic jam assist, park assist level 2)</p>	<p>Inattention: as automation becomes more able and reliable, drivers will inevitably do things other than pay attention to driving.</p> <p>Feedback: knowing the state of the automation is of paramount importance and this is not straightforward. On the one hand, users rely on their memory of having pushed a button and habitually ignore system-status displays. On the other hand, automation functions sometimes turn off without any apparent reason and lacking an appropriate feedback.</p>

LEVEL OF AUTOMATION (NHTSA)	HUMAN FACTORS PROBLEMS
3 (e.g. traffic jam chauffeur, highway chauffeur, highway pilot)	<p>Rapid onboarding: users have great difficulty re-establishing driving context and this is especially worse when the situation is complex.</p> <p>Skill atrophy: cognitive skills deteriorate when not practiced regularly but hands on skills seem to be resistant to forgetting (Casner et al., 2014). However, cognitive skills are needed first to determine what manual operations are required.</p> <p>Complexity: drivers are less trained compared to pilots of an airplane, which creates critical situations where the automation complexity results in unexpected behaviours. When drivers are unexpectedly asked to resume control of the car, they are likely to experience difficulties to get back in the loop, assess the situation and be able to respond in time.</p>

Source: Own elaborations (based on results from Casner et al., 2016).

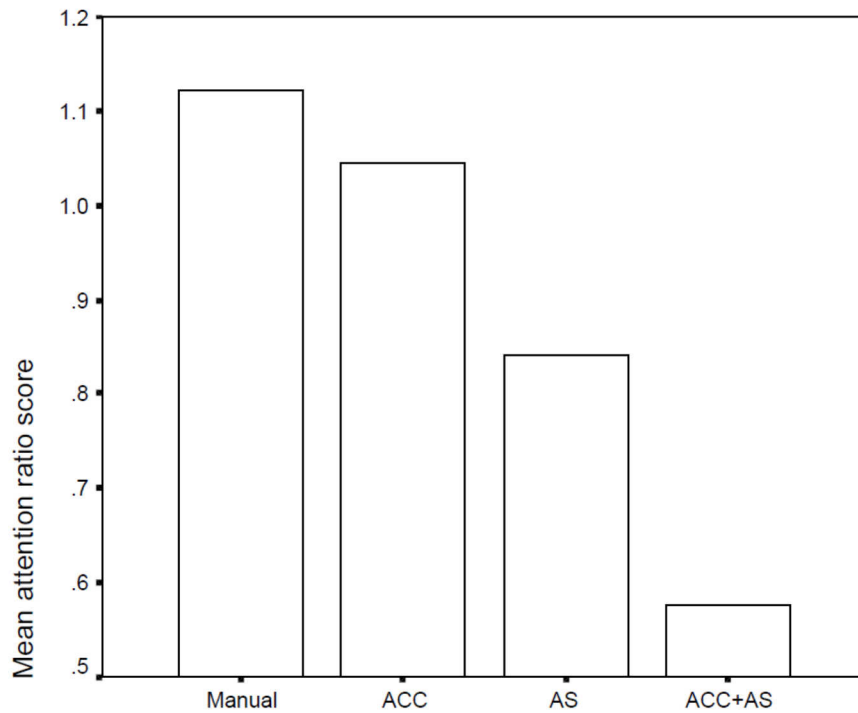
In a 2007 publication (Stanton et al., 2007), Stanton, Young and Walker discuss with Professor Don Norman (lead expert in design, usability engineering and cognitive science) about the psychological aspects of the driver when designing automation into vehicles. The authors provide evidence from laboratory researches suggesting that the theoretical spare attentional capacity resulting from automation of longitudinal and lateral vehicle control is unlikely to exist given that attentional resources are not fixed but instead they are inextricably linked to task demand. They specifically addressed Adaptive Cruise Control (ACC) and Active Steering (AS) systems and investigated their effects on driver performance and more specifically on mental workload. They found that some levels of automation lead to underload, which is understood to be as bad as overload, and provide an explanation based on the Malleable Attentional Resources Theory (MART). This theory proposes that resources may actually shrink to accommodate any demand reduction, as opposed to the "work expands to fill the time available" tenet (see Figure 16). This explains the observed degradation of attention and performance in low demand tasks, meaning that the maximum capacity of the driver is limited as a consequence of the task, and supports why drivers cannot cope when a critical situation arises (see Figure 17). Conversely, other studies found that participants invest more effort with higher time pressure, which may increase capacity (Liao and Moray, 1993 as cited in Stanton et al., 2007). Only at medium levels of demand are resources, and hence performance, optimised. Thus, MART suggests that excessively low mental workload such as may be the case of automation, could result in a reduction of attentional resources. As also expressed by the authors, automation does not prepare the driver for emergencies as they do not use the spare capacity to engage in additional hazard detection and emergency response preparation activities.

**Figure 16.** Relation between task demands and performance under a malleable attentional resources model



Source: Young and Stanton, 2002 (as cited in Stanton et al., 2007) (Inderscience retains copyright of the figures and article).

**Figure 17.** Attention ratio scores across each automation condition (ACC and/or AS)



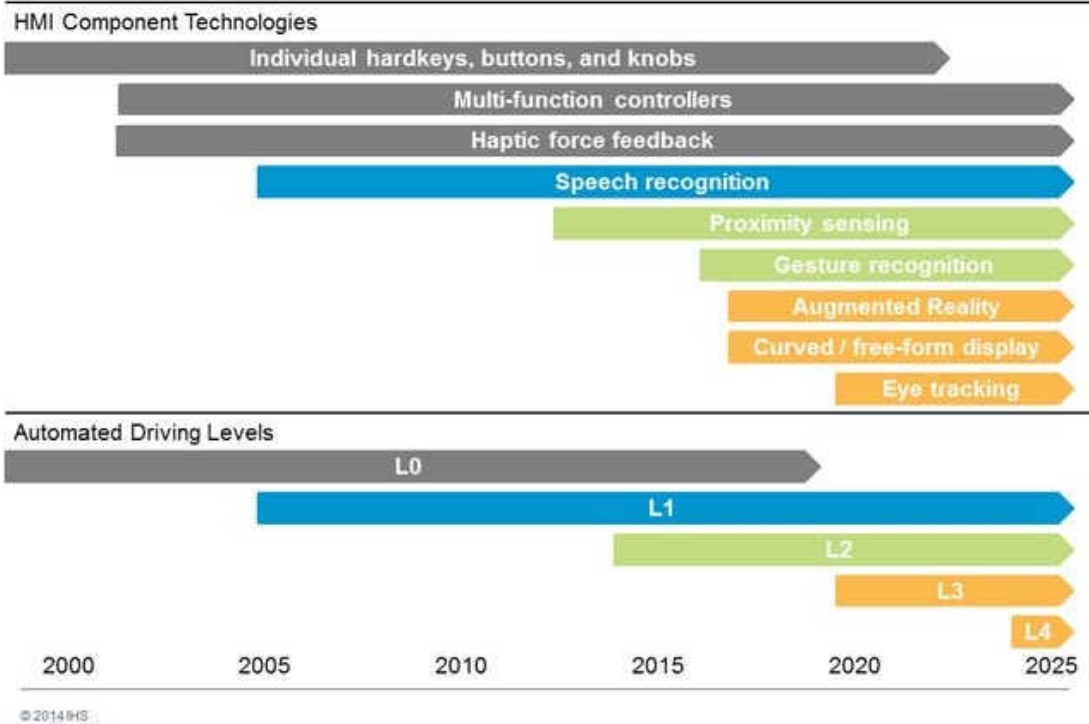
Source: Young and Stanton, 2002 (as cited in Stanton et al., 2007) (Inderscience retains copyright of the figures and article).

These previous studies highlight the problems linked to taking the driver out of the loop and thus the need for a strong consideration of human factors issues in automated driving (especially in partial automated driving), with the final aim of minimising the risks imposed on safety. In this context, driver status monitoring might be beneficial.

### 3.3.2 Human-Machine Interface

The information and warnings judged to be relevant for the driver are given via the Human-Machine Interface (HMI). The HMI can rely on visual, acoustic and haptic channels for conveying information to the users, used either separately or combined. In the latest years, the in-vehicle’s HMI has evolved by incorporating in the car some of the functionalities available in smartphones, i.e. allowing mobile devices to be operated through the car’s dashboard screen. Android Auto is the standard developed by Google, while CarPlay is the one developed by Apple. Mirrorlink is an intermediate solution between both platforms which is compatible with either of the two operating systems, Android and iOS. Among the functionalities offered, there is navigation, messaging, music playback, internet search. This increases in-car connectivity and allows a plethora of information and entertainment services available to the driver and passengers. The future automated driving will allow for further digital interactions, profiting from driver’s transition from driving to non-driving tasks and making use of innovative forms of interaction (e.g. augmented reality, gestures recognition) (Boyadjis, 2015; see Figure 18).

**Figure 18.** The interconnection of HMI and automated driving (according to NHTSA levels)



Source: Boyadjis, 2015.

It is in the intermediate levels in which the DDT is performed by both the driver and the vehicle that important Human-Machine Interaction (HMI) concerns emerge. As defined by the International Harmonized Research Activities (IHRA) Working Group on ITS (IHRA WG ITS, 2010), the notion of driver-in-the-loop means that a driver is involved in the driving task and is aware of the vehicle status and road traffic situation as an active player of the driver-vehicle system. On the contrary, out-of-the-loop means that the driver is not immediately aware of the vehicle and the road traffic situation because he/she is not actively monitoring, making decisions or providing input to the driving task (Kienle et al.,



2009). The HMI has a key role in keeping the driver in the loop, by informing the driver of required status information transparently and unambiguously. This means that systems need to be designed to detect the limits of their own range of effectiveness during highly automated driving and clearly inform the driver (visually, haptically and acoustically) with sufficient advance time to be able to resume the driving task <sup>(15)</sup>. A recent study found that resuming control in automated driving requires up to 5 seconds more than conventional driving (Kühn, 2016). Specifically, the authors found that after a drive with a high level of distraction, 90% of the drivers looked at the road again for the first time after 3-4 seconds, had their hands back on the steering wheel and their feet on the pedals after 6-7 seconds and had turned off the automated system after 7-8 seconds. Even drivers who were not distracted at the moment where the request of intervention came, had delayed reactions compared to users in normal manual driving.

When it comes to proposing best practices for AVs HMI, the following recommendations can be highlighted (Kühn, 2016):

- The driver needs to be notified as early and clearly as possible of the need to resume vehicle control (preceded by an early identification of the need to transfer the vehicle control). The takeover period must last longer than 8 seconds.
- The automated system must remain active during the takeover process, until the driver has shown readiness to take over vehicle control.
- A minimum risk manoeuvre has to be put in place if the driver cannot handle the control takeover request.
- Comprehensive but succinct information on the current driving situation needs to be provided in order to facilitate the driver's situational awareness after an automated drive.
- The vehicle readiness to assist after the driver has resumed control needs to be increased to avoid inappropriate reactions of the driver.
- To show the urgency of a given situation, a cascade of different types of warnings could be issued to the driver.
- Instructions about capabilities and limitations of automated systems could be specifically given to drivers for better user reactions in the event of a control takeover request and to avoid wrong or reduced system use.

Standardising HMI could be beneficial to minimise the risk for users' misunderstanding/confusion when using different AV models, especially in consideration of the car sharing trend.

About interaction with other road users outside the vehicle, a 2015 study (Lagström and Lundgren, 2015) on the pedestrian - driver communication provided the following interesting insights. Pedestrians need to know when a vehicle is in automated mode, given that the decoupled driver's inattentive behaviour can otherwise be interpreted as uncertain and dangerous and may as a consequence impede the pedestrian to cross. This investigation proposed an external HMI prototype with LED strip lights showing different sequences depending on the AV intended manoeuvre: about to yield, about to start, resting or in automated driving mode. The prototype evaluation delivered promising conclusions as regards the suitability of having an external HMI. The users who participated in this study were able to understand the interface messages after a short training. They reported that the interface could replace the role of the driver and even excel today's interaction as the communication was clearer and available earlier.

NHTSA also provided a set of HMI considerations (NHTSA, 2016a). Constantly showing the system status is highlighted as a minimum requirement for AV systems (e.g. whether it is properly functioning or requesting a driver's intervention). In fully automated systems, the

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<sup>(15)</sup> See VDA's Networked and automated driving site, <https://www.vda.de/en/topics/innovation-and-technology/automated-driving/automated-driving.html>.



need to design an HMI that accommodates for people with disabilities is explicitly indicated. For fully automated vehicles that operate without any humans in it (e.g. automated delivery vehicles), the central control authority or remote dispatcher should know the status of the operated AVs at all times. Driver engagement monitoring for those systems that may require drivers to regain vehicle control is suggested. Equally relevant, the consideration of signalling vehicle intentions to other road users such as pedestrians, cyclists and other vehicles. Since this is an area which is rapidly evolving, a special mention is given to considering the guidance, best practices, and design principles published by SAE International, ISO, NHTSA, American National Standards Institute (ANSI), among others.

Further research in this area may be required to better understand the AV interface needs.

### **3.3.3 User acceptance**

Users adoption and integration of automated driving technologies in their everyday lives will be ultimately influenced by different factors including trust, users acceptance (comprising perceived usefulness, ease of use and satisfaction), knowledge (comprising knowledge of function and problem perception), compliance with social norms and personal values and willingness to pay (including perceived affordability and desirability) (Karlsson et al., 2011). According to the theory of Diffusion of Innovations (Rogers, 1995), there are four main contributory elements: the innovation (including aspects such as relative advantage, compatibility, complexity, trialability and observability), the communication channels (e.g. mass media), time (from first knowledge to adoption, influenced by the innovativeness of an individual: innovators, early adopters, early majority, late majority and laggards) and the social system (e.g. existing cultural and religious norms, external influences and interpersonal information). Overall users' acceptance of AVs is gradually improving, but is anyway an issue to be properly tackled as it can potentially be a barrier to actual systems use.

For example, a UK study (FIA, 2015 <sup>(16)</sup>) found that half of the respondents would not trust manufacturers and government assuring that AVs are safe. Only 38% of the respondents agreed that AVs would be as safe as human driven ones. Results of a 2014 survey (Schoettle and Sivak, 2014a) revealed that although most respondents had a positive impression of the automated driving technology, a large percentage of them said they had concerns that AVs would not drive as well as human drivers (a 90.1% said they had some level of concern). At EU level, a special Eurobarometer study conducted in 2014 on autonomous systems found that 61% of the respondents would not feel comfortable travelling in an autonomous car (European Commission, 2015g), with men and young people being more prone to feel comfortable with the technologies. As opposed to these results, a French study (Payre et al., 2014) showed that 68.1% of the 421 participants who answered an online questionnaire, a priori accepted AVs. Almost 71% of respondents declared an interest in using AVs while being impaired (e.g. alcohol, medication affecting driving). According to this research and in line with other studies, men showed a stronger intention to use an AV and were more inclined to use and buy one. Likewise, the higher the driving-related sensation-seeking, the more drivers intended to use an AV. A strong positive correlation was also found between attitudes and intention to use an AV. The preferred use cases were monotonous and stressful driving conditions such as highways, traffic congested situations and parking. However, AVs would be less used in built-up areas according to the findings of this study, probably because drivers felt more confident in their own skills compared to the vehicle in situations where road hazardous circumstances can occur more frequently.

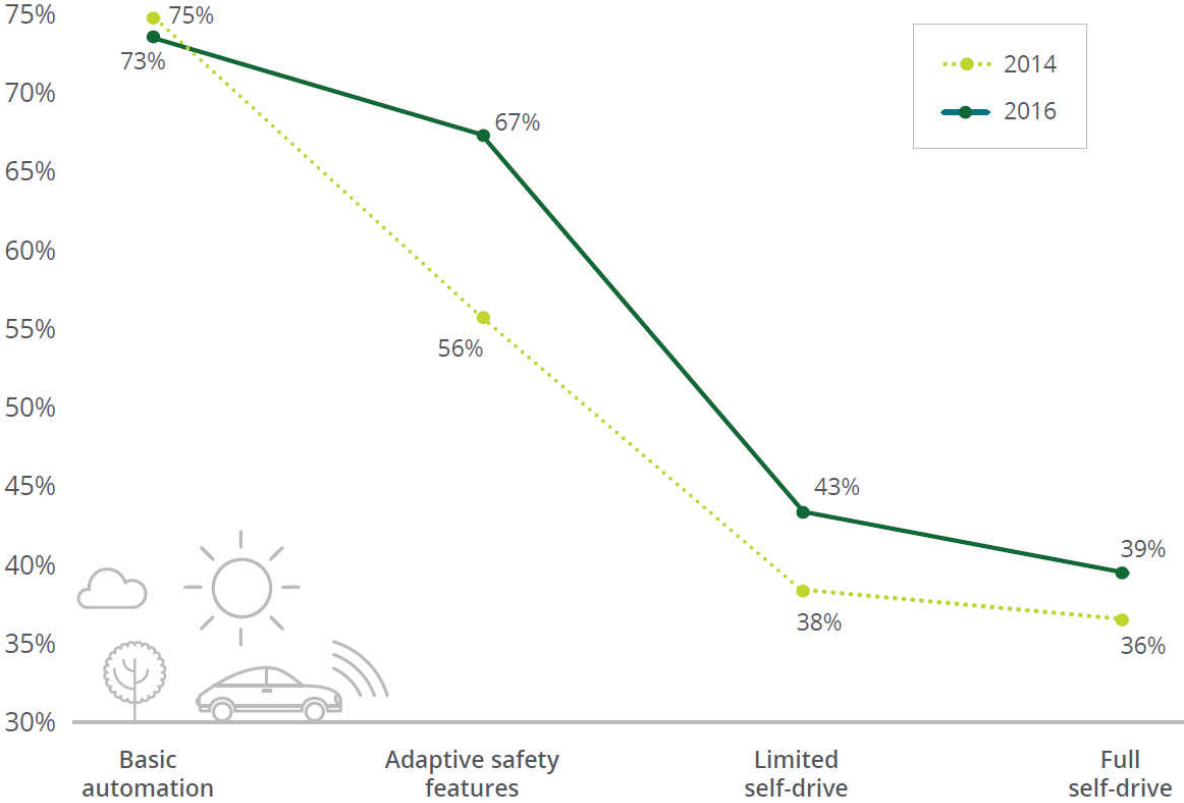
Overall, users' acceptance towards AVs is slowly improving as people are starting to experience more and more with the technologies through the existing demonstration and marketing activities of the various manufacturers and technology companies. A survey (Giffi et al., 2017) found that US consumer interest in advanced vehicle automation has

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<sup>(16)</sup> AA Populus poll based on 21,202 members answers (2012) (cited in FIA, 2015).

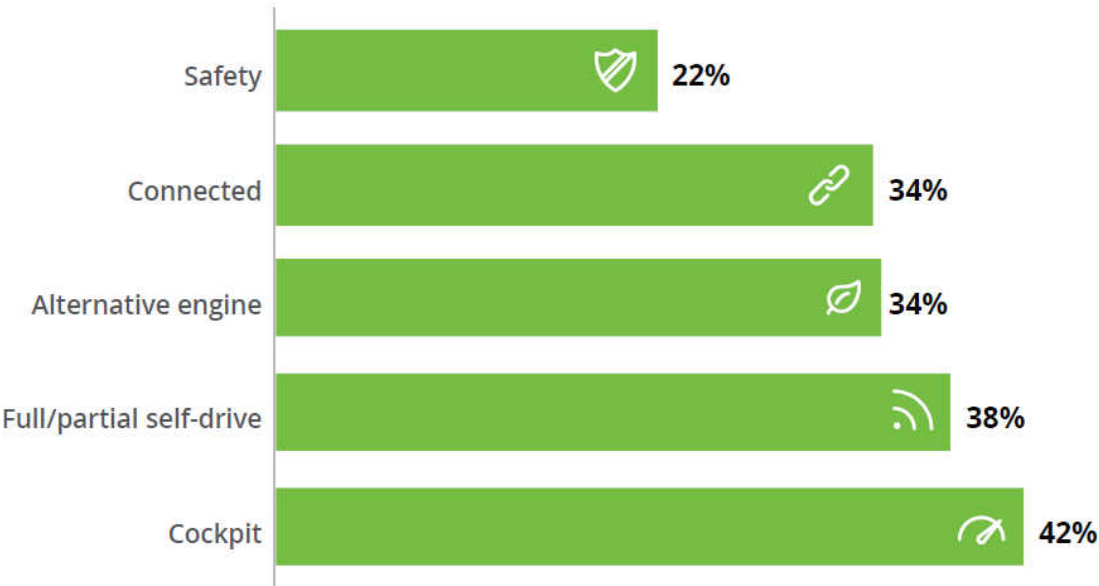
increased since 2014 (see Figure 19), especially among the younger generations. Safety-related applications are the most valued ones. On the contrary, users' willingness to pay for these technologies has decreased since 2014 (see Figure 20).

**Figure 19.** Percentage of US consumers interested in automation technology (2014-2016 comparison)



Source: Giffi et al., 2017 (Copyright © 2017. Deloitte Development LLC. All rights reserved).

**Figure 20.** Percentage of US consumers not willing to pay for vehicle features



Source: Giffi et al., 2017 (Copyright © 2017. Deloitte Development LLC. All rights reserved).

A recent study involving 12,000 survey respondents from 11 European countries plus 48 focus group participants from 4 European countries focused on how drivers feel about interacting with an AV (Tennant et al., 2016). The study yielded the following results. 44% of the respondents stated they would feel uncomfortable about using an AV while 41% stated they would feel uncomfortable about driving alongside an AV. Although 43% of the users agreed that AVs would be safer than human driven vehicles, a 73% of them fear that AVs could malfunction and 60% believe that AVs would lack the common sense needed to interact with human drivers. Most of the respondents (60%) acknowledged that they don't know enough about AVs but users became more positive the more they reflected on AVs while responding to the survey. Most of them believe that human should be in control of their vehicles (70%) and AVs should have a steering wheel (80%). 82% of the respondents would prefer to keep attentive to the road situation even when the vehicle is in full control of driving. Users who are more sociable and less optimistic about technology are the least open to AVs and on the contrary, users who have a more combative view of the road and are more technologically optimistic are those more open to AVs. A 34% of respondents said they did not like the idea of mixing human drivers and AVs, with only 20% of users not troubled by the idea.

Also, a recent study based on system demonstrations under real circumstances (Piao et al., 2016) found positive users attitudes towards the implementation of AVs in urban areas, being driven by factors such as lower fares. Concerns about passenger security (e.g. during night time services) were expressed though. Although more than half of the people surveyed stated that they would consider using AVs, only a quarter of the respondents believed AVs would be safer than conventional ones, which indicates low levels of awareness and/or understanding of the technologies and therefore the need for real experiences with the systems. Therefore consumers are gradually building trust on AVs which will eventually have an influence on the adoption rate of these technologies. The more complex a product is, the slower the rate of adoption that can be expected (Karlsson et al., 2011). The easier it is for individuals to see the results of the use of an innovation, the more likely they are to adopt it (Karlsson et al., 2011). Surprisingly, a recent study about users preferences for using AVs in last mile trips (Yap et al., 2016) found that travellers on average associate more disutility to the in-vehicle time in an automatically driven AV, compared to a manually driven AV, which can be possibly explained with the discomfort feeling that travellers might experience when imagining riding in a driverless automobile. Users lacked real experiences with the use of an AV though. This result can also be explained in relation to the fact that they were just considering the use of AVs for the egress part of the whole trip, thus for a relatively short part of the total multimodal trip. User attitudes play an important role in the actual use of AVs as last mile transport mode, e.g. attitudes towards the sustainability of AVs and perception of trust were the most important attitudinal factors for using AVs. Also, the joy of driving is of relevance for users choice of travel mode, which is reflected in users favouring the choice of the manually driven AV. Contrary to what was initially expected, attitudes regarding service reliability and work productivity had a secondary role in the total utility, indicating that the potential advantages of using an AV are not perceived by today's travellers. The study suggests to incorporate these psychological factors before and during the implementation process of AVs, as they may have a great influence on users' future adoption of the technologies.

Similarly, connected vehicles face potential barriers from the users' side. A study on the quality of transport (European Commission, 2014b) found that 41% of respondents would not be willing to connect their vehicles. Of those who would be willing to have a connected vehicle (51%), a 38% stated that this would be conditional to data anonymity or the possibility to decide when to be connected. A more recent survey (Mobile World Live, 2017) found that a 60% of the respondents expected connected car roll-outs to be well underway within two years from 2016 and a 36.4% of them stated that deployments were already happening in their countries. Although network technology was not seen as a significant issue (only 11.6% of respondents identified insufficient bandwidth or throughput as an issue), a 36.6% of them identified irregular network coverage as the main connectivity

deficiency that has potential to hold the market back. Security is seen as a concern, with a majority (60%) agreeing with the statement: “I don’t know how to secure my connected car application or where my weak links are”.

The Fraunhofer IAO (Dungs et al., 2016), in collaboration with management consultants Horváth & Partners, surveyed 1,500 motorists as part of the "Value of Time" study regarding their willingness to pay for in-car value-added services. Based on the results of the survey each motorist is willing to pay on average 20 and 40 euros per month for value-added services in an AV. The more popular automated driving becomes, the greater the demand by users for services to meaningfully utilize the time freed up in the car. Offers related to service and communication are the most heavily in demand though with different variations. For example, interest in in-car social media services is much higher in Japan than in Germany (64% compared with 23%). Finally, the willingness to pay for services related to AVs reduces significantly from the age of 35 but it is not related to the vehicles segment, i.e. whether the motorist is a driver of small, mid-sized or high-end vehicle.

### 3.3.4 Preliminary human factors requirements for C-ART

Building on previous subsections, the following table provides a list of preliminary human factors requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration.

**Box 1.** Summary of human factors aspects of relevance for C-ART

#### **The C-ART system would initially require:**

- Given that C-ART would ideally work with highly automated vehicles, a dedicated in-vehicle interface that passengers can use for non-driving related activities would be convenient. In it, C-ART relevant informative messages could be included.
- C-ART could also consider using an external vehicle HMI so that pedestrians, cyclists, PTWs can stay informed about the relevant vehicle intentions.
- Probably the most relevant aspect in the context of C-ART is users’ acceptance and overall users experience with the system, as it will directly influence the real system use.

#### **Key remaining open questions are:**

- How to manage a mix of AVs and conventional vehicles? (Problems arising from their interaction? Is retrofitting of old vehicles possible?)
- Should drivers have the right and freedom to overrule the controller's decisions? (Always, on certain time periods or in specific areas?)
- What is the users’ perception of AVs? (Trust? Losing joy of driving? Willingness to buy one? Willingness to pay for services? Safety, efficiency and environmental impact influencing their choice? Interaction with pedestrians?)
- Which new business models may appear? (New mobility services?)
- Need for consumer education and training?

## 3.4 Data

As it has already been indicated in section 2.3, the increasing amount of data which is available with transport technologies has enormous potential for the optimization of the transport system. In addition, this data offers potential for new business model creation (e.g. mobility as a service). As specified in (GEAR 2030, 2016b), around 30-40 % of the value in the automotive value chain will pass through digital platforms in the near future. Increasing digitalisation of the vehicles will underscore the importance of the access to data (GEAR 2030, 2016a).

The recent communication by the European Commission on building a European data economy (European Commission, 2017a), as part of the Digital Single Market strategy, aims at fostering the best possible use of the potential of digital data to benefit the economy and society and addresses the barriers that impede the free flow of data to achieve a European single market. The EU data economy was valued at €272 billion in 2015 and is estimated to increase to €643 billion by 2020, representing 3.17% of the overall EU GDP. Results from the ongoing public consultation will feed into the Commission's possible future initiative on the European Data Economy in 2017.

*"The connected vehicle and connected infrastructure requires available data transmission frequencies, low-latency, trusted, secure and fail-safe data transmission protocols and harmonised data syntax that ensures safe interoperability"* (OECD/ITF, 2015a). Aspects like data sharing, security and privacy are of paramount importance in this context. For instance, sharing AV crash and incidents data would contribute to the improvement of AV technologies, learning from real accident data in order to make AVs safer (Tillemann and McCormick, 2016). Cybersecurity is a prerequisite in the increasing digitalised transport, protecting networks, computers, programs and data from attack, damage or unauthorized access. The protection of personal data and privacy is also an essential aspect of automated and connected driving technologies offering end-users transparency and control over their data. The main data challenges are discussed in the next subsections.

### **3.4.1 Data collection, recording and sharing**

As described in the NHTSA policy guidance document (NHTSA, 2016a), *"data should be collected for both testing and operational (including for event reconstruction) purposes"*. The whole process covering data collection, recording, sharing, storage, auditing, and deconstruction of recorded data (including but not limited to crash events) must be strictly in accordance with the manufacturer's consumer privacy and security agreements and notices (NHTSA, 2016a). NHTSA requires that crash data is stored, maintained and readily available for retrieval by the entity itself and by NHTSA. It specifies some minimum crash-related data to be recorded and states the following as regards the sharing of these data: *"Manufacturers or other entities should have the technical and legal capability to share the relevant recorded information"*. It also highlights the value in collecting data of correct system operation, especially in the successful avoidance of events, incidents or crashes. A plan for sharing event reconstruction and other relevant data with other entities is recommended to be developed. Data shared with third parties should be de-identified, i.e., removing elements that direct or reasonably link to a specific AV owner or user. It needs to be in accordance with privacy and security agreements and notices applicable to the vehicle or with owner/user consent. NHTSA suggests that the industrial partners collaborate with relevant standards bodies (e.g. IEEE, SAE International) to develop a uniform approach to address data recording and sharing.

Within GEAR 2030 Working Group 2 on automated and connected vehicles, the use of data storage for liability purposes is being discussed (GEAR 2030, 2016b). With expectations that data storage will become mandatory at some point to establish whether the driver and/or the AV are in charge of vehicle control when an accident occurs, a set of specific requirements would need to be developed. Data storage should be part of the Type Approval Regulatory framework and should deal with a number of related aspects: data integrity, data privacy and cybersecurity. Data integrity refers to the validation of data storage. Data privacy and data security are further elaborated in the subsections below. The access to this data also needs to be regulated, distinguishing who is accessing the data (law enforcement authorities, repairers, insurers, manufacturers, parts suppliers, software companies) and whether there is a legitimate interest (like e. g. determination of responsibility). The General Data Protection Regulation (GDPR) is the framework for this.

According to Intel CEO Brian Krzanich (Nelson, 2016), one AV will generate around 4,000 GB of data every day (corresponding to one hour of driving) (see Figure 21). In another estimation provided by Tom Lüders, director of testing solutions at Hella Aglaia, during the

1<sup>st</sup> European Connected and Automated Driving conference, this number can be even bigger and reach 7.4 Tb per day per vehicle (Kelly, 2017).

**Figure 21.** Daily data generated by an AV



Source: Nelson, 2016.

HERE submitted a universal data format design under the name SENSORIS to ERTICO – ITS Europe (Castle, 2016), who agreed to evolve the design into a standardized interface specification for broad use across the automotive industry. SENSORIS is actually a forum comprising HERE, AISIN AW, Robert Bosch, Continental, Daimler, Elektrobit, HARMAN, NavInfo, PIONEER, TomTom, among others. The objectives of this forum are to enable broad access, delivery and processing of vehicle sensor data; to support the easy exchange of vehicle sensor data between all players; and to enable enriched location-based services. Based on the SENSORIS initiative that provides a format for car-to-cloud data, HERE acknowledged to be working on the creation of a data sharing platform that ensures that all vehicles are speaking the same language (Dano, 2017). For a right functioning of safety applications, automotive manufacturers will have to align their data communications and their application development (Dano, 2017).

Linking the vehicle with the transport infrastructure is a priority area within the ITS Directive 2010/40/EU (European Union, 2010), and this includes the definition of an open in-vehicle platform.

### **3.4.2 Data privacy**

*"The protection of personal data and privacy is a determining factor for the successful deployment of cooperative, connected and automated vehicles"* (European Commission, 2016a). Connected vehicles (i.e. C-ITS) are able to generate, store and transmit users' personal data like current location, route to work, time of driving, history of journeys, favourite music, appointments, banking and payment data, etc. Vehicle owners and vehicle users should have the right to decide if and how their data is used. This data has a significant potential for other uses and as it can be accessed and used by third parties (especially sensitive driver and driving related data), legislation to protect personal privacy of consumers in connected vehicles is necessary (Gleave et al., 2016). Hence, compliance with the applicable data protection legal framework is required, namely Directive 95/46/EC (until 24 May 2018) and Regulation (EU) 2016/679 - General Data Protection Regulation (applicable from 25 May 2018 onwards). In this context, the Free Flow of Data (FFD) initiative of the European Commission in the framework of the Digital Single Market aims

at removing the data localisation restrictions and thus, at providing the freedom to process and store data in electronic format anywhere within the EU <sup>(17)</sup>.

As explained in (European Commission, 2016a), *“data protection by design and by default principles and data protection impact assessments are of central importance in the basic C-ITS system layout and engineering, especially in the context of the applied communication security scheme”*. If these conditions are met, the willingness of end-users to give consent to broadcast data is not a barrier, in particular for applications enhancing road safety or improving traffic management (NHTSA, 2016a). In this communication, the following specific actions on privacy and data protection are identified by the Commission to ensure coordinated deployment of C-ITS services in 2019:

- *“C-ITS service providers should offer transparent terms and conditions to end-users, using clear and plain language in an intelligible way and in easily accessible forms, enabling them to give their consent for the processing of their personal data.*
- *The Commission will publish first guidance regarding data protection by design and by default, specifically related to C-ITS, in 2018.*
- *The C-ITS deployment initiatives should:*
  - *work on information campaigns to create the necessary trust among end-users and achieve public acceptance;*
  - *demonstrate how using personal data can improve safety and efficiency of the transport system while ensuring compliance with data protection and privacy rules;*
  - *consult with EU Data Protection Authorities to develop a sector based data protection impact assessment template to be used when introducing new C-ITS services.”*

In the NHTSA policy guidance document (NHTSA, 2016a), a list of principles on privacy are given, including transparency; choice; respect for context; minimization, de-identification and retention; data security; integrity and access; and accountability. Relevant references include inter alia the 2014 Privacy Principles for Vehicle Technologies and Services published by the Alliance of Automobile Manufacturers and the Association of Global Automakers (Alliance of Automobile Manufacturers and the Association of Global Automakers, 2014), the OECD guidelines on the protection of privacy and transborder flows of personal data (OECD, 2013).

### **3.4.3 Data security**

Adding communication capabilities to vehicles creates security risks as third parties could have uncontrolled access to vehicle data, jeopardising the safety of the vehicle, occupants and other road users as well as the privacy of passengers and other citizens. These risks include system intrusion, personal data theft, cyberphysical attacks, data corruption, among others. The different networks in the vehicle (i.e. infotainment, chassis control, power train, body control), which are interconnected by a central gateway, have diverse security requirements and risks (see Figure 22). In the case of AVs, vehicle manufacturers develop, implement and manage software and hardware extensions (Gleave et al., 2016). *“The connection between the in-vehicle system and the manufacturer's central server has to be secure, so that all data transfers are protected from unauthorised disclosure and manipulation”* (Gleave et al., 2016). Vulnerability cases have been discovered in the past. For instance, in 2015, hackers took control of a Jeep over the internet, revealing a security hole in Fiat Chrysler Automobiles' Uconnect internet-enabled software (Gibbs, 2015). In the same year, an attack was performed by security researchers on the BMW ConnectedDrive and managed to remotely unlock vehicles (C't magazine für computer

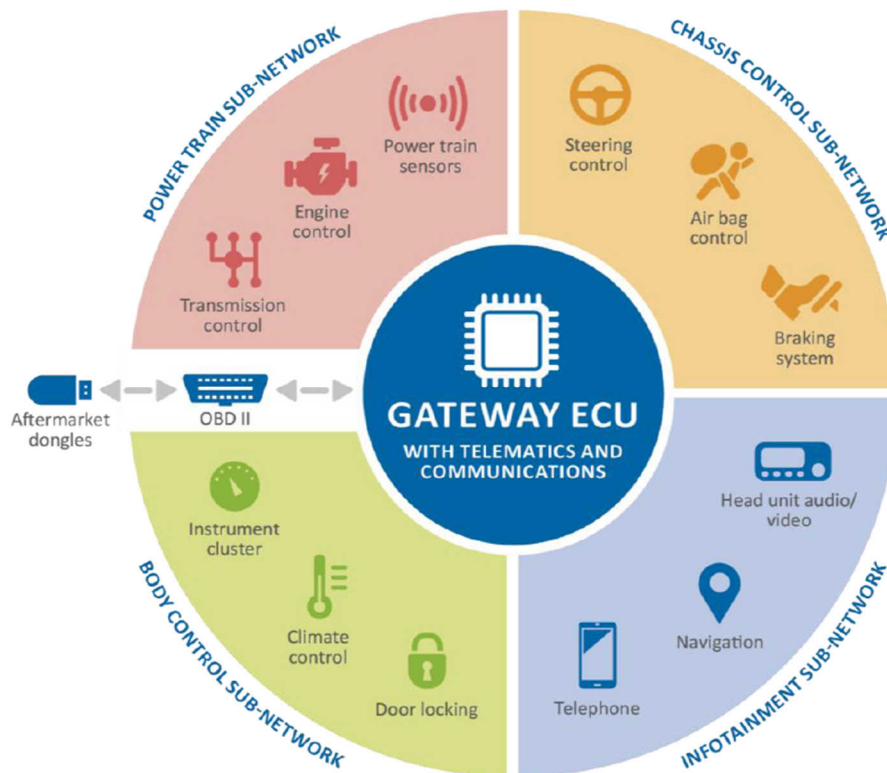
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<sup>(17)</sup> See European Commission Digital Single Market site on *“Building a European Data Economy”* <https://ec.europa.eu/digital-single-market/en/building-european-data-economy>, last accessed 22 February 2017.



technik, 2015). Similarly, in 2016, security researchers discovered how to use Software Defined Radio (SDR) to remotely unlock different brands of vehicles including Volkswagen, Alfa Romeo, Citroën, Fiat, Ford, Mitsubishi, Nissan, Opel, and Peugeot (Gitlin, 2016). Another example is the attack made by researchers from the Chinese Keen Security Lab who remotely manipulated the brake system on a Tesla while it was on the move (Lee, 2016).

**Figure 22.** High level architecture of a smart car



Source: ENISA, 2016 (© European Union Agency for Network and Information Security (ENISA)).

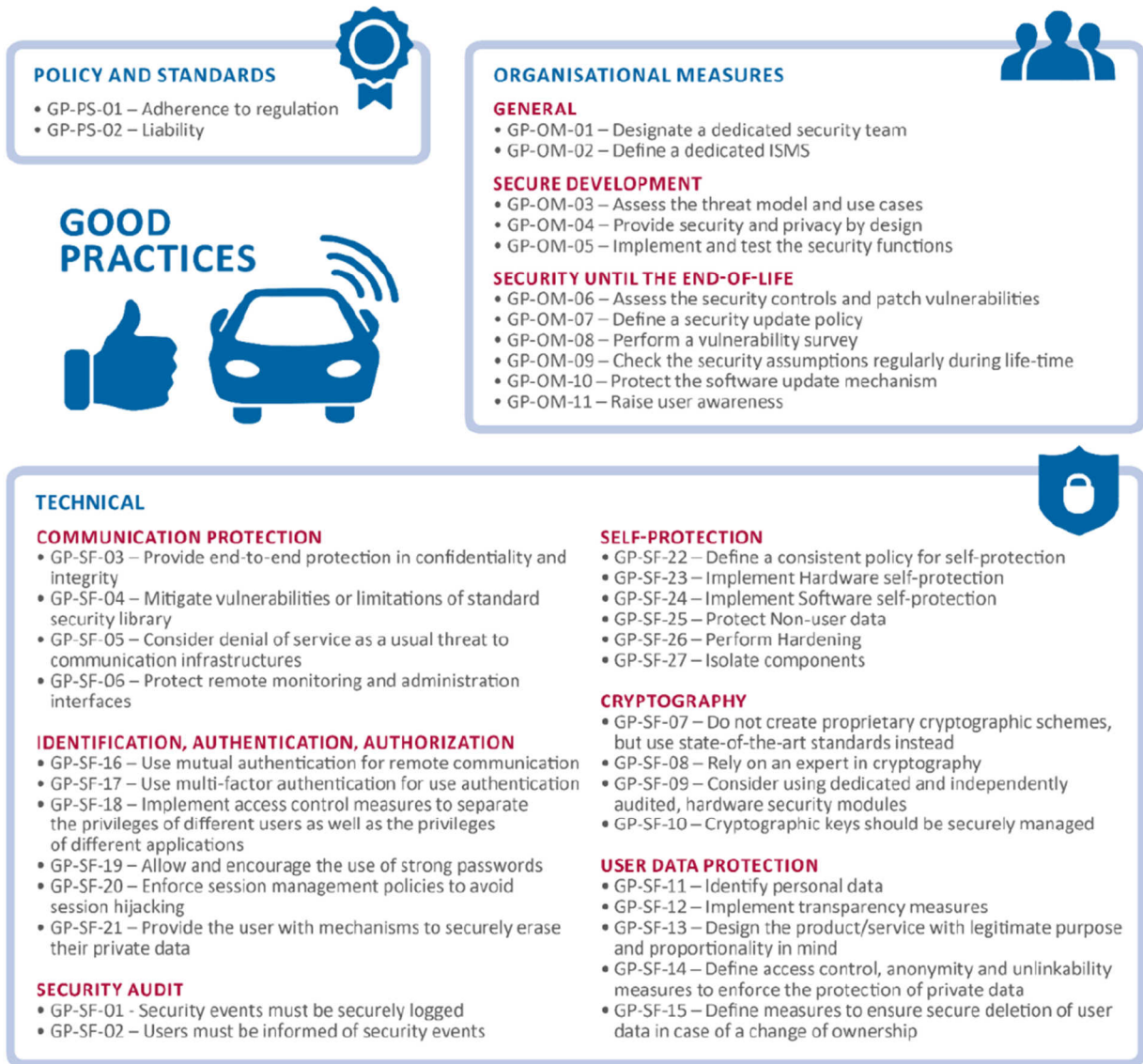
In (European Commission, 2016a) the cyber-security of C-ITS communications has been acknowledged as being critical and requiring action at European level. There is a need for clear rules, adopted at the Union level, avoiding fragmented security solutions which will put interoperability and the safety of end-users at risk. An EU-wide security framework for the deployment and operation of C-ITS in Europe, based on Public Key Infrastructure technology (defined in this context as the combination of software, asymmetric cryptographic technologies, processes, and services that enable an organization to secure C-ITS communications) and addressing vehicle and public infrastructure elements (including a compliance assessment process) is needed. Working on a common security solution for C-ITS will serve as preparatory work for stronger security at higher levels of automation. The following specific actions on security of C-ITS communications are identified:

- *“The Commission will work together with all relevant stakeholders in the C-ITS domain to steer the development of a common security and certificate policy for deployment and operation of C-ITS in Europe. It will publish guidance regarding the European C-ITS security and certificate policy in 2017.*
- *All C-ITS deployment initiatives should participate in the development of this common security policy by committing from the beginning to implement future-proof C-ITS services in Europe.*



- *The Commission will analyse the roles and responsibilities of the European C-ITS Trust Model, and whether some operational functions and governance roles should be taken over by the Commission (as, for instance, in the case of the Smart Tachograph)."*

**Figure 23.** Summary of good practices to ensure the security of smart cars



Source: ENISA, 2016 (© European Union Agency for Network and Information Security (ENISA)).

The ENISA report recently published (ENISA, 2016), although not explicitly addressing automated vehicles or connected vehicles, maps the current threats that passengers and drivers are exposed to on a daily basis, both as private vehicle users and commercial vehicle users. It identifies good practices that ensure the security of smart cars against cyber threats, divided into three categories: Policy and standards, Organizational measures and Technical. Good practices are summarised in the figure below (Figure 23). Then, the following recommendations are given:

*“Recommendations for smart car manufacturers, tiers and aftermarket vendors:*

- *Improve cyber security in smart cars. The industry actors should establish the good practices that effectively enhance the security of their products.*

- *Improve information sharing amongst industry actors. Information sharing helps industry actors challenge the relevance of their security mechanisms according to field information. Communities for information sharing already exist, and we recommend pursuing this effort.*
- *Improve exchanges with security researchers and third parties. Industry actors should enhance their contacts with third parties, especially from the security domain.*

*Recommendation for smart car manufacturers, tiers, aftermarket vendors and insurance companies:*

- *Clarify liability among industry actors. Living in heavily-tiered environment, industry actors should define processes to clarify their respective liability in case that security issues arise.*

*Recommendation for industry groups and associations:*

- *Achieve consensus on technical standards for good practices. The good practices listed in this report are meant as an input for a standardization effort, rather than being directly applicable to a specific car design. The details of the security requirements should be defined in the context of standards.*
- *Define an independent third-party evaluation scheme. The existing safety standards for automotive systems only marginally address security, and we recommend to define an independent evaluation scheme.*

*Recommendation for industry groups and associations and security companies:*

- *Build tools for security analysis. Industry actors can directly improve their security testing skills by building tools for security testing and security monitoring."*

In the NHTSA policy guidance document (NHTSA, 2016a), cybersecurity is covered by instigating manufacturers and other entities to follow a robust product development process based on a systems-engineering approach, including systematic and ongoing safety risk assessment for the AV system, the overall vehicle design into which it is being integrated and, when applicable, the broader transport ecosystem. The following established best practices for cyber physical vehicle systems are suggested to be considered by manufacturers and other relevant organizations. In particular, the Alliance of Automobile Manufacturers (AAM) formed in 2014 a voluntary Information Sharing and Analysis Centre (Auto ISAC) to target the threat of hackers (McCarthy et al., 2014). An ISAC (Information Sharing and Analysis Center) is a trusted, sector-specific entity that can provide a 24-hour per day and 7-day per week secure operating capability that establishes the coordination, information sharing, and intelligence requirements for dealing with cybersecurity incidents, threats, and vulnerabilities. Sharing lessons learned on cybersecurity is as important as the sharing of the data itself. Therefore, reporting on cyber vulnerabilities to the Auto-ISAC is strongly encouraged. Adopting a vulnerability disclosure policy is also encouraged.

### **3.4.4 Preliminary data requirements for C-ART**

Building on previous subsections, the following table provides a list of preliminary data requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration (some of them shared with the technology section).

**Box 1.** Summary of data aspects of relevance for C-ART

**The C-ART system would initially require:**

- To ensure data privacy and data security in the data handling and sharing that C-ART will require among the different actors.

**Key remaining open questions are:**

- Which data are required by the AVs for a fast, safe, reliable and efficient mobility? (Devices needed? Synergies with enabling technologies like 5G or Galileo? Data requirements? Which data to be provided and maintained by road transport authorities? Which types of data will need management? Do we need to store all data? Data privacy concerns? Security concerns?)
- How to manage huge amounts of data? (Transmission problems? Latency issues? Do we consider the same order of volumes for individual AV management as for C-ART management or are these two different approaches? Which data can be shared?)
- Could C-ART data be useful for other purposes/services?

### 3.5 Ethics

In the absence of laws, ethics or moral philosophy come into play. The so called “Trolley Problem” by Philippa Foot (Thomson, 1985) describes a situation in which a trolley is about to crash with five workmen standing on the track. Brakes are not working but there is the possibility of turning right. However, in this new track there is one workman. If you turn the trolley, this man will die. Is it morally permissible for you to turn the trolley? In front of such a situation, there is a moral difference between killing and letting die. Doing something that causes someone to die seems worse than allowing someone to die as a result of events that you were not responsible for.

While there has been a lot of public discussion on the potential ethical dilemmas that an AV could face, clear conclusions are still lacking. A plausible reason for that is that no choice is more valid than others (Hars, 2016). In addition, it is being wrongly assumed that AVs would be able to know certain characteristics of individuals and the consequences of every action with certainty (Hars, 2016). Also, the probability of facing such situations in real life is extremely low (Hars, 2016). The request which is being made by our society is that AVs avoid making ethically wrong decisions, rather than requiring them to positively take ethically correct decisions (Hars, 2016). The question is whether we are going to treat machines equally under such situations or whether we would blame them for having premeditatedly chosen a given outcome (killing someone instead of letting die).

Three more realistic scenarios presenting ethical dilemmas have been identified by Brooks (Brooks, 2017): illegal parking at Starbucks, evening event with few nearby parking lots and, giving children a lift to school.

To encourage reflections on this area, the MIT developed a Moral Machine (Rahwan et al., 2016) that guides users through a set of scenarios to understand what they would do in front of such circumstances. In this context, Mercedes Benz stated that they would always prioritise saving the driver and passengers of the car (Taylor, 2016).

#### 3.5.1 Preliminary ethical requirements for C-ART

Building on previous ideas, the following table provides a list of preliminary ethical requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration.

**Box 1.** Summary of ethical aspects of relevance for C-ART

**The C-ART system would initially require:**

- The C-ART system should not penalise any user when implementing the journey decisions, thus proper care should be given in the definition of rules and criteria governing the C-ART real time decision making process.

**Key remaining open questions are:**

- Is there any specific ethical judgement of relevance for C-ART?

### 3.6 Insurance and liability

AVs will involve a transfer of liability from vehicle owners/drivers to vehicle and/or systems manufacturers. Liability laws are an aspect of utmost importance in this new context and will directly affect public confidence on these new technologies. As vehicles become more complex with highly automated systems and connectivity, liability assignment also gets more complicated. To support this, the use of data storage in AVs would provide valuable information on the circumstances in which the accident took place. Independently of who is held liable in case of an accident, traffic victims need to receive compensation (as considered in the Motor Insurance Directive 2009/103/EC). The principle of strict liability is applicable by prioritizing the compensation to traffic victims before determining who is held liable for the accident. The Product Liability Directive 85/374/EEC is equally relevant in this context. The insurance industry will see a change in their sales as higher levels of autonomy are available in the market, with greater proportions of commercial and product liability lines, while personal automobile insurance shrinks (Albright et al., 2016). Further information on the legal framework for insurance and liability is given in subsection 3.7.3.

Insurance companies are using data collected during driving to determine usage-based insurance policies that offer discounts to users on the basis of when and how they drive. This data also enables improved customer segmentation and marketing campaigns and opens the floor to new business opportunities (Löffler et al., 2016).

#### 3.6.1 Preliminary insurance and liability requirements for C-ART

Building on previous ideas, the following table provides a list of preliminary insurance and liability requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration.

**Box 1.** Summary of insurance and liability aspects of relevance for C-ART

**The C-ART system would initially require:**

- That an appropriate legal insurance and liability framework is adopted, relying on data recordings and storage to determine who was in control of the vehicle at a given point in time.

**Key remaining open questions are:**

- Could the C-ART manager be held liable in case of an accident or damage?

### 3.7 Policy and legislation

Researchers, industry and regulators are becoming more and more interested in automated driving technology, automated transport and expected beneficial impacts on reducing road fatalities, energy consumption and environmental pollution. Policymakers cannot be fully aware of all the implications that may derive from automated driving but they are obliged to adopt a forward-thinking approach based on the outcomes from the research community and the industry. Policy making acts as an enabler, in an effort to maximise the benefits while decreasing to a minimum the disadvantages associated to automated driving technology through an optimal mixture of policy instruments. In the early stages of the transition from conventional driving towards full autonomy, open competition between different models and initiatives is necessary to instigate creativity and innovation (European Union, 2016). However, industry and users demand that new services and systems are interoperable and compatible when crossing borders. As stated in the Declaration of Amsterdam, important steps have been taken by the EC (e.g. C-ITS platform, Round Table on Connected and Automated Driving, GEAR 2030 initiative), but a more coordinated approach across the EU is called upon, to remove existing barriers and promote a step-by-step learning-by-experience approach, supporting the exchange of information and best practices.

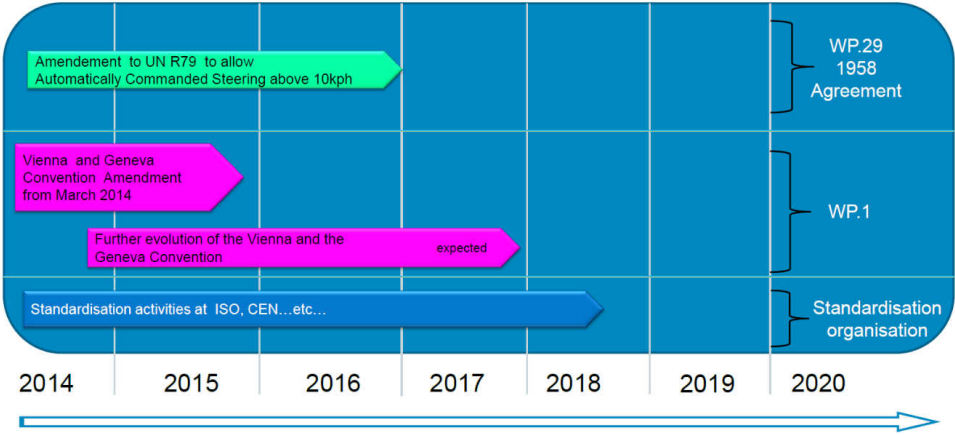
This section reviews the international and European policy and legal situation in the field of connected and automated vehicles. An important reference has been the following European Parliament report (Gleave et al., 2016) and GEAR 2030 roadmap (GEAR 2030, 2016b).

In general, driving systems belonging to levels 0 to 2 do not face major legal obstacles. However, for higher degrees of automation (levels 3, 4 and 5) and for connectivity, EU legislation may need to be modified or new legislation may need to be introduced. For instance, aspects such as traffic rules, connectivity, driving license, road worthiness, liability, road signs, insurance, theft and cybersecurity, privacy and data protection, compliance assessment. The work being conducted by the United Nations Economic Commission for Europe (UNECE) at international level is fundamental to prevent the existence of legislative barriers that limit the introduction of oncoming automation systems while at the same time it paves the way for future highly automated systems. In particular, the UNECE Inland Transport Committee (ITC) is a platform for international cooperation to facilitate the international movement of persons and goods by inland transport modes. The ITC has two permanent subsidiary bodies whose work is relevant for the introduction of automated driving:

- the Working Party on Road Traffic Safety (WP.1), which is a permanent intergovernmental body responsible for administering the international road-traffic related conventions including the 1968 Vienna Convention on Road Traffic and the 1968 Vienna Convention on Road Signs and Signals;
- the World Forum for Harmonization of Vehicle Regulations (WP.29), which is a permanent intergovernmental body, responsible for the harmonisation of technical vehicle requirements.

WP.29 prepares the work of the ITC to develop and adopt harmonised vehicle regulations. Specifically through the UN WP.29, three kinds of uniform automotive standards exist: on the one hand, "Global Technical Regulations" (GTR) and "UN Regulations" which evaluate the performance of vehicle components and subsystems (UN Regulations are intended specifically for use within the international type-approval system; to the extent that GTR and UN Regulations treat the same subject, UN Regulations are required to conform with the provisions of their respective GTR); on the other hand, "UN Rules" concern the harmonization of vehicle inspection requirements to facilitate international road traffic. According to the 2014 progress report by the European Commission on the major regulatory developments and activities in WP.29 (European Commission, 2014a), the Commission notes its expectation that in the coming years the regulatory framework for AVs will be progressively placed as a priority topic on the WP.29 agenda. The activities planned within WP.29 and WP.1 in relation to automated driving are presented below (see Figure 24). The timing for the implementation of standards is crucial as regulating too late will result in different standards, but regulating too early could stifle innovation.

**Figure 24.** Automated driving in UN regulations



Source: Esser, 2015.

In the report regarding automated driving technology and the policymakers' perspective (Anderson et al., 2016), the authors highlight some key milestones towards fully automated vehicles on the roads. Among others, it should be clear whether the use of AVs would require additional regulation or not and how its safety should be tested and by whom. Other issues need to be clarified such as liability, implications of a non-harmonized framework and a set of additional regulations regarding smart infrastructure, dedicated highway lanes, etc. In a recent intervention by Ms. Melanie Schultz, Minister of Infrastructure and the Environment from The Netherlands, made during the 1<sup>st</sup> European Conference on Connected and Automated Driving, the need to have a more dynamic and forward-looking regulatory framework was highlighted, pointing at the possibility of creating rules for transport in general rather than by mode of transport (Schultz, 2017). She also stressed the importance of learning by doing. A review of the existing legal and policy framework applying to testing and place into market of automated and connected vehicles is presented below, covering the international, European Union and national situations. This framework covers issues such as inter alia road safety, vehicle approval, driver behaviour, liability in case of an accident, processing of personal data.

On an international level, the Transport Ministers of the G7 States and the European Commissioner for Transport agreed in September 2015 on a declaration on automated and connected driving (European Commission, 2015d). In it, the connected and automated vehicle is labelled as the "third place", i.e. a key connected place in addition to people's homes and offices, which enables a productive timeframe while moving from one place to another. The developments in the field of automated and connected driving are supported, highlighting the need to establish a harmonized regulatory framework that enables a safe deployment of these technologies across national borders. Automated driving will require sustained cooperation among the G7 transport ministers and the European Commissioner for Transport on the following: coordinating research, promoting international standardisation within an international regulatory framework, evolving technical regulations and ensuring data protection and cyber security. A second meeting among the Transport Ministers of the G7 States and the European Commissioner for Transport took place in September 2016, where the importance of research in the areas of human-machine interface, infrastructure and social acceptance was also highlighted and it was decided to establish a dedicated working group to work on well designed and globally harmonized future looking regulations and other measures.

From an international point of view, we also highlight the work done by the Harmonization Task Group (HTG) with the collaboration of US DOT, the JRC and DG CNECT and the Transport Certification Authority (TCA), whose longer-term goal is to harmonize ITS-related standards between the U.S. and Europe (European Commission and US Department of Transportation, 2012). A set of functional specification and recommendations for cybersecurity of C-ITS were published in 2015 (European Commission, 2015e).

The European Commission is also promoting connectivity and interoperability by working on the international harmonisation of technical standards, together with the European Standardisation Organisations and in cooperation with the US/EU Standardisation Harmonisation Working Group.

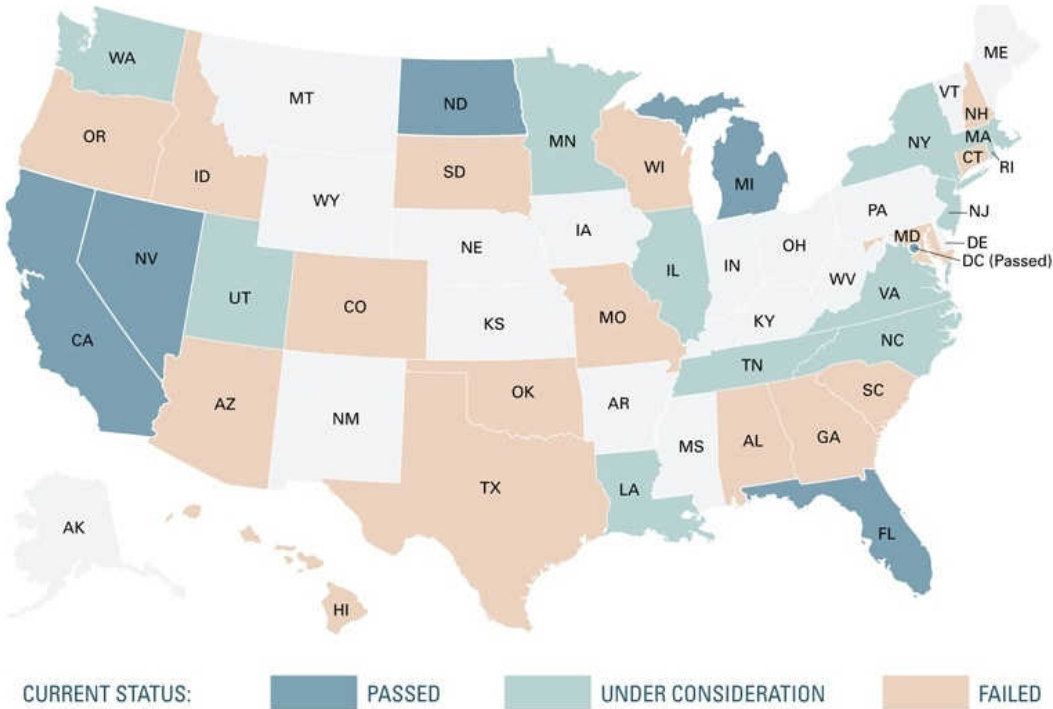
Efforts to permit testing of highly automated systems have been made worldwide, either by granting authorisation on a case by case basis (e.g. Japan) or by modifying national laws (e.g. United States).

Internationally, bilateral relations with Japan and the USA offer great opportunities to use world-wide knowledge to tackle the challenges of connected and automated road transport and share expertise, data and facilities. For example, the Commission intends to "twin" EU-funded projects with similar ones funded by the US Department of Transportation.

In the beginning of 2016 the US announced to invest in a 21st century transport system. According to the press release from Department of Transportation (DoT) of the United States (US Department of Transportation, 2016), the budget proposal (FY17) would provide nearly \$4 billion over 10 years for pilot programs to test connected vehicle systems

in designated corridors throughout the country, and work with industry leaders to ensure a common multistate framework for connected and automated vehicles. It is worth mentioning that one of the milestones set was NHTSA to work with industry and other stakeholders in order to provide a common understanding of the performance characteristics necessary for fully automated vehicles and the testing and analysis methods needed to assess them. To date, in the United States there are 8 states that allow for testing of AV technologies: California, Florida, Nevada, Louisiana, Michigan, North Dakota, Tennessee and Utah. Among these states, the first three of them (California, Florida and Nevada) have laws allowing for the operation of automated cars beyond testing. Both California and Nevada require vehicles to store sensors data from 30 seconds before a collision. The California Department of Motor Vehicles (CA DMV) recently proposed regulations for all AVs to have manual controls with the ability for a human driver to regain control in emergency situations. Contradicting part of the federal guidelines, the California regulation is seen as a major hindrance by AVs developers who aim to remove the human driver from the equation entirely, with Google arguing that the risk is that human occupants may be tempted to override the self-driving system’s decisions, reintroducing the human error situations that account for a significant proportion of road accidents. Florida's 2016 legislation expands the allowed operation of AVs on public roads and eliminates requirements related to the testing of AVs and the presence of a driver in the vehicle. On a US level, since 2012, at least 34 states and Washington D.C. have considered legislation related to AVs, many of them failing to pass related bills (National Conference of State Legislatures, 2017; Weiner and Smith). The status of US regulations as of October 2016 is shown in the figure below (Figure 25).

**Figure 25.** US regulations on automated driving



Source: Riehl, 2016.

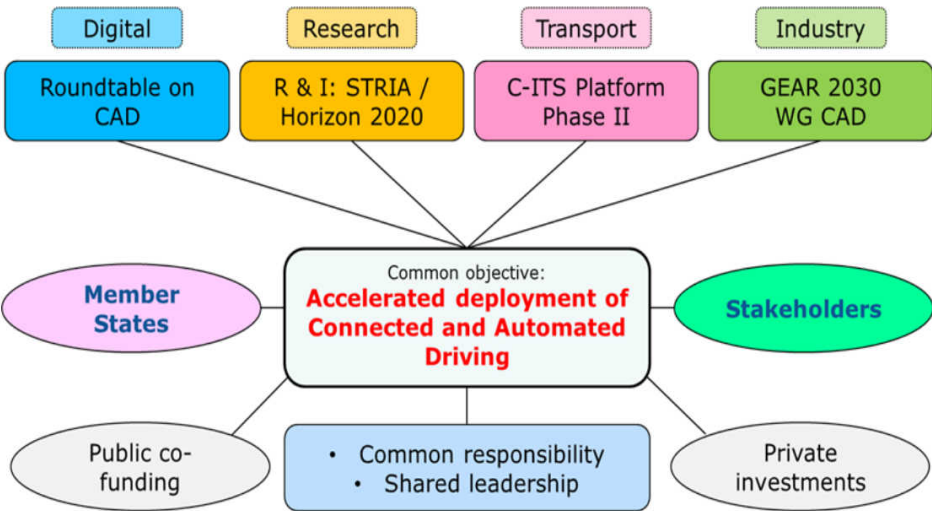
In the US regulatory context, a significant contribution to the deployment of automated driving technologies is the early 2016 response from the National Highway Traffic Safety Administration (NHTSA) to Google on the interpretation of “driver” (NHTSA, 2016b), where NHTSA stated that the driverless computer Google created to pilot its self-driving cars can be considered, under federal law, a “driver”. The NHTSA released its Preliminary Statement of Policy Concerning Automated Vehicles on May 30, 2013 (NHTSA, 2013). In an effort to establish a consistent nationwide framework to allow the safe design, development, testing



and deployment of highly automated vehicles (HAVs), the NHTSA recently released a guidance document containing regulations for HAVs (NHTSA, 2016a). Included in the document are issues of crash liability, regulatory language and how to approach distracted driving. According to the guidance document, States retain their traditional responsibilities for drivers licensing and registration of motor vehicles, traffic laws and enforcement and motor vehicle insurance and liability regimes. NHTSA responsibilities comprise setting and enforcing compliance with Federal Motor Vehicle Safety Standards (FMVSS), issuing guidance for vehicle and equipment manufacturers, managing non-compliances and safety-related defects and recalls, and communicating and educating the public about motor vehicle safety issues. Vehicle manufacturers are invited to voluntarily submit a safety assessment letter to the U.S. DOT’s Office of the Chief Counsel for each AV system. The policy lists 15 points that should be considered and "checked off" before any public implementation of the technology: Data Recording and Sharing, Privacy, System Safety, Vehicle Cybersecurity, Human Machine Interface, Crashworthiness, Consumer Education and Training, Registration and Certification, Post-Crash Behaviour, Federal, State and Local Laws, Ethical Considerations, Operational Design Domain, Object and Event Detection and Response, Fall Back (Minimal Risk Condition), Validation Methods. The policy is currently issued as guidance, and is "not intended for states to codify as legal requirements for the development, design, manufacture, testing and operation of automated vehicles." During a public hearing on the policy on Nov. 10 2016, representatives mostly from vehicle manufacturers voiced recommendations for the structure and content that should be required in the letter (McCauley, 2016). Overall three main recommendations surfaced: need for further clarifications, need to ensure that confidential data is protected and need to keep the safety assessment letter’s regulations as simple as possible. The group of automakers and tech firms Self-Driving Coalition for Safer Streets has called on U.S. regulators to change federal auto safety standards that effectively prohibit the operation of a car without the presence of a driver (Beene, 2016).The group, whose founding members are Ford Motor Co., Google, Volvo, Uber and Lyft, wants the NHTSA to amend certain Federal Motor Vehicle Safety Standards that limit fully automated vehicles and have also called on the Congress to enact legislation to aid self-driving car deployment.

The situation in Japan is dealt with on a case by case basis. Japan signed the Geneva Convention but not the successive Vienna Convention. Test permissions are individually granted by authorities and always require the presence of a driver in the vehicle at all times. Nissan was the first manufacturer to obtain an official permission to test AVs in Japan in 2013 and recently (March 2016) a special permission was granted to test Robot Taxi AVs.

**Figure 26.** EC initiatives in Connected and Automated Driving



Source: Rogge, 2016.



In the European Union, connected and automated vehicles are given a high priority and a number of initiatives have been put in place over the last years (see some EC initiatives in Connected and Automated Driving in Figure 26).

In terms of R&I, since a long time, ITS, connected and automated vehicles are among the priorities of the EU's research and innovation efforts. The Strategic Transport R&I Agenda (STRIA), as a key component of the Energy Union's R&I strategy, dedicates one thematic transport research area to cooperative, connected and automated transport. Specifically, within the Horizon 2020 Framework Programme for Research and Innovation, a call has been devoted to automated road transport, with a budget of over €100 million over a 2-year period. As automated and connected vehicles require a high-performance infrastructure, the Connecting Europe Facility (CEF) and the Investment Plan for Europe are also key financing mechanisms that have as important targets to stimulate investment in broadband networks and transport infrastructure and hence prepare the transition from research, development, and demonstration to market deployment. In the context of STRIA, the EC is currently developing a roadmap on connected and automated transport to steer and coordinate R&I activities and policies in Europe.

The European Parliament highlighted the importance of ITS in making transport more efficient, safer, secure and environmentally cleaner (European Parliament, 2009) and the need to overcome barriers to interoperability, a lack of efficient cooperation among all actors, as well as data privacy and liability issues. Besides, the European Parliament emphasized that digitalisation is vital to improving the efficiency and productivity of the transport sector and recognized the need to provide an enabling regulatory framework for pilot projects aimed at the deployment of intelligent automated transport in Europe (European Parliament, 2015).

The C-ITS Deployment Platform was set up in 2014 as a cooperative framework among national authorities, C-ITS stakeholders and the Commission, to develop a shared vision on the interoperable deployment of C-ITS in the EU. The first milestone towards cooperative, connected and automated vehicles in the EU was achieved last year with the endorsement of the final report of the first phase of the C-ITS Platform (C-ITS Platform, 2016). Based on the recommendations from the platform, the Commission prepared the European Strategy on C-ITS, a milestone initiative towards cooperative, connected and automated mobility (European Commission, 2016a), to contribute to a wide-scale commercial deployment of C-ITS by 2019. The JRC was involved in the drafting of both the final report of the first phase of the C-ITS Platform and the European Strategy on C-ITS, in particular, the key concepts of the trust model for C-ITS. Furthermore, the C-ROADS Platform was launched in 2016 as an authority driven platform pursuing the harmonisation of C-ITS deployment activities across Europe with the goal of achieving the deployment of interoperable cross-border C-ITS services for road users <sup>(18)</sup>. Likewise, the Amsterdam Group was created as a strategic alliance of key stakeholders (including CEDR, ASECAP, POLIS and Car2Car Communication Consortium) that aim to facilitate the joint deployment of C-ITS in Europe <sup>(19)</sup>. At present, the second phase of the C-ITS Platform is ongoing, with a particular focus on the links between connectivity and automation, specifically covering infrastructure and road safety issues, and the drafting of the Certificate Policy for the European trust model for cooperative ITS.

During the Frankfurt Motor Show in September 2015, the European Commissioner for Digital Economy and Society, met representatives of the automotive and telecommunications industries to discuss strategies for an accelerated deployment of cooperative, connected and automated driving (European Commission, 2015c). Key players from both sectors participated in this Round Table, including BMW, Continental, Daimler, Bosch, Renault, Valeo, Vodafone, Deutsche Telekom, Tele2, among others. An agreement was issued (ETNO, 2015) setting the basis for collaboration between the sectors and expressing commitment to work on common roadmaps to accelerate the development and deployment of cooperative, connected and automated driving, including issues such

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<sup>(18)</sup> See C-ROADS Platform website <https://www.c-roads.eu/platform.html>, last accessed 10 April 2017.

<sup>(19)</sup> See Amsterdam Group website <https://amsterdamgroup.mett.nl/default.aspx>, last accessed 10 April 2017.

as connectivity, mobile network coverage and reliability, the take-up of cooperative, connected and automated driving, security and privacy. Afterwards, a second Round Table on cooperative, connected and automated driving was held during the 2016 Paris Motor Show, this EU cross-sector dialogue was formalised in the form of the European Automotive-Telecommunications Alliance (EATA) (European Competitive Telecommunications Association, 2016). The Alliance includes 6 leading sectorial associations and 37 companies, including telecom operators, vendors, automobile manufacturers and suppliers for both cars and trucks. Its main goal is to promote the wider deployment of cooperative, connected and automated driving in Europe through a comprehensive, large-scale and cross-border approach. It is actively working on a pre-deployment project which will include use cases such as automated driving, road safety and traffic efficiency and digitalisation of transport and logistics. A third Round Table on cooperative, connected and automated driving was recently held in the Mobile World Congress 2017 in Barcelona, chaired by Vice-President Ansip and Commissioner Oettinger, acknowledging the progress made on the development of a cross-border pre-deployment project and sharing plans for the next steps. In parallel, the 5G Automotive Association was created in September 2016, joining automotive manufacturers (including e.g. BMW, Audi, Daimler, Ford) with telecommunications companies (such as Ericsson, Huawei, Intel, Nokia, Qualcomm Incorporated, Deutsche Telekom) to develop, test and promote communications solutions, having cooperative, connected and automated driving as part of their focus (Nica, 2016). We note that 5G is a different set of communication standards in comparison to the ETSI DSRC 5.9 GHz standards already defined to support cooperative ITS in Europe. The role of 5G in cooperative, connected and automated vehicles should be further clarified and it may require additional research and testing before 5G is deployed in this domain.

In the beginning of 2016, the Commission launched the GEAR 2030 High Level Group for the automotive industry to ensure a coordinated approach at Union level and address the challenges and opportunities that the European automotive industry will face (European Commission, 2016c). Participants of GEAR 2030 are: Member States, industry, representatives of consumers, trade unions, environmental protection, road safety, ITS and selected observers. One specific area of work is related to cooperative, connected and automated vehicles. GEAR 2030 is assisting the Commission in developing a long-term EU strategy for highly automated and connected vehicles by the end of 2017.

The Declaration of Amsterdam, Cooperation in the field of connected and automated driving (European Union, 2016), was signed in April 2016 by the 28 transport ministers of the European Union Member States. All parties agreed to work towards a coherent European framework for the deployment of interoperable cooperative, connected and automated driving. With a view to achieving this objective, a set of actions were defined for Member states, the European Commission and industry to support the introduction of cooperative, connected and automated driving and achieve its full potential. The Declaration of Amsterdam has instigated different public and private actors to initiate activities aiming at making cooperative, connected and automated driving a reality. Following the declaration, a high level structural dialogue on cooperative connected and automated driving has been recently held in Amsterdam (CLEPA, 2017). Although developments on cooperative, connected and automated driving have accelerated since the Declaration of Amsterdam, the actions laid down in the declaration need to be boosted in order to be ready for the deployment of cooperative, connected and automated driving by 2019.

Very recently, during the Digital Day in Rome on 23 March 2017, 29 European countries signed a Letter of Intent with the purpose of intensifying their cooperation on cross-border testing of automated road transport (European Commission, 2017b).

At a Member States level:

- Sweden is a signatory country of the Vienna Convention. Thus, the Vienna Convention coexists with the Swedish Road Traffic Ordinance and several regulations have been incorporated from the Convention into national legislation. The latter requires the presence of a driver in the vehicle capable of intervening at all times. Automotive

manufacturers are required to demonstrate that their automated systems do not affect basic driving tasks and allow the driver to always maintain the control of the car. Also local authorities and municipalities are authorised to issue special traffic laws and define regulations independently from national directives, but these special authorisations are only granted for situations that guarantee safety at all times.

- France also signed the Vienna Convention. With their focus on allowing AVs deployment, they authorised automated vehicles testing in 2014 and defined specific zones where tests are allowed (with new zones to be introduced soon). Peugeot-Citroën was the first manufacturer to obtain an authorisation. Official standards are expected to be operative by 2020.
- Germany, as signatory country of the Vienna convention, has recently agreed on a draft act that would allow the transfer of vehicle control from the driver to the highly or fully ADS (Gesley, 2017). The driver would still need to be in the car and is obliged to take over the driving functions from the ADS without undue delay following a request by the driving system or if he/she realizes that the conditions for using the ADS are no longer fulfilled. It foresees that a black box records who is in control of the vehicle at any time.
- Similarly, Belgium requires a driver to be present in the car during the testing of automated vehicles in national roads, under the responsibility of car manufacturers and subject to permissions from regional authorities as owners of the infrastructure and the federal administration that has to approve the technology installed in the vehicle.
- Netherlands is also a signatory of the Vienna Convention. It aims at building a regulatory framework to allow AVs to be tested in the country. In 2015 it approved an amendment to its national regulations authorising the national road traffic agency to grant exemptions for large-scale testing of self-driving cars and trucks on public roads.

UK does not present major legal obstacles to test automated vehicles on public roads, especially as they have not ratified the Vienna Convention. The efforts of the UK government as regards the regulatory framework that will be introduced by summer 2017 are focused on providing light regulations to ensure that manufacturers and suppliers can easily test and develop automated vehicles. The Department for Transport (DfT) has published a non-statutory Code of Practice that organisations testing automated vehicles in the UK are expected to follow. It specifically provides guidelines and recommendations for measures that should be taken to maintain safety during testing. Moreover, in July 2015 the UK government launched a £20 million competitive fund for collaborative research and development into automated vehicles.

### **3.7.1 Road traffic**

In most of the Member States, the driver behaviour is covered by traffic rules, civil and criminal law to ensure road safety. Road users owe a duty of care to other road users and in case breaching that duty causes damage, they will be held liable. The assumption at present is that there is a natural person as the driver of a vehicle, therefore being responsible for the safe operation of the vehicle. In the light of automated driving technologies, the driver will be partially or completely replaced by computers and therefore a new regulatory framework will be needed.

The *1968 Vienna Convention on Road Traffic* and the previous *1949 Geneva Convention on Road Traffic* are international treaties designed to facilitate international road traffic and enhance road safety by establishing standard traffic rules among the contracting parties. The Vienna Convention enables cross-border road transport. Article 8 of the 1968 Convention on Road Traffic stipulates the following: “*Every moving vehicle or combination of vehicles shall have a driver. Every driver shall possess the necessary physical and mental ability and be in a fit physical and mental condition to drive. Every driver of a power-driven vehicle shall possess the knowledge and skill necessary for driving the vehicle... Every driver shall at all times be able to control his vehicle or to guide his animals*”, thereby requiring that a driver is always fully in control and responsible for the behaviour of a vehicle in traffic. In 2006, the following paragraph was added: “*A driver of a vehicle shall*

*at all times minimize any activity other than driving. Domestic legislation should lay down rules on the use of phones by drivers of vehicles. In any case, legislation shall prohibit the use by a driver of a motor vehicle or moped of a hand-held phone while the vehicle is in motion*". However, in order to accommodate for partially automated systems the Vienna Convention was recently amended. The amendment agreed by the United Nations Working Party on Road Traffic Safety (WP.1) in March 2014 would allow a car to drive itself, as long as the system "can be overridden or switched off by the driver". It anyway requires that a driver is present and able to take the wheel at any time, therefore driverless vehicles are not yet allowed according to the Convention. The amendments came into force on the 23rd of March 2016, allowing for automated driving technologies transferring driving tasks to the vehicle to be used in traffic, provided that these technologies are in conformity with the UN vehicle regulations or can be overridden or switched off by the driver. A similar amendment is being prepared to the Geneva Convention. Additionally, article 13 of the Vienna Convention also creates a conflict: "Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him. He shall, when adjusting the speed of his vehicle, pay constant regard to the circumstances, in particular the lie of the land, the state of the road, the condition and load of his vehicle, the weather conditions and the density of traffic, so as to be able to stop his vehicle within his range of forward vision and short of any foreseeable obstruction. He shall slow down and if necessary stop whenever circumstances so require, and particularly when visibility is not good". Consequently, to this point in time, the Vienna Convention is still incompatible with high or full automation, i.e. level 4 and level 5 systems, and further amendments will be necessary to accommodate self-driving vehicles. In this context, to address the introduction of highly automated systems, UN WP.29 has engaged in discussions with the Working Party on Road Traffic Safety WP.1 to address inconsistencies between the Convention and WP.29 regulations. The Vienna Convention has been ratified by 73 countries to date. It is noteworthy that among others, the United States, Japan and China are non-signatory countries of the Vienna Convention and within Europe, Spain and UK have not ratified it. Nevertheless, USA and Spain are signatories of the Geneva Convention on road traffic, which is somewhat more flexible as to driver's obligations and better accommodates for automated driving. In addition, national traffic rules apply in each country, for example in Germany, the Strassenverkehrsordnung (StVO) or in Spain, the Ley sobre Tráfico, Circulación de Vehículos a Motor y Seguridad Vial. Traffic rules at a Member state level will need to be updated to incorporate the use of highly automated systems. Specifically, those countries that have signed the Vienna Convention would need to align their national traffic regulations accordingly. These legal frameworks presently constitute a barrier to the implementation of highly automated technologies and require careful attention in the short/medium term.

### **3.7.2 Driving licence**

*Directive 2006/126/EC* establishes the minimum requirements for driving licences. Currently, this legal framework does not create any obstacle to the use of automated vehicles as it does not seem necessary to include any additional competence requirements for drivers. In addition, national legislation applies at the level of Member States. As far as professional drivers are concerned, *Directive 2003/59/EC* on training and initial qualifications of professional drivers might need to be examined (e.g. for trucks platooning).

### **3.7.3 Insurance and liability**

There is currently no harmonisation at EU level of the rules on liability in case of damages caused by accidents involving motor vehicles, but rather different liability regimes across EU Member States. Most of these regimes are based on the concept of causality of the accident to determine who is held liable. However, with more and more automation, it will be increasingly complicated to identify the exact cause of an accident (i.e. whether it is a hardware defect or a software malfunction or an inadequate driver's behaviour). On the

one hand, *Directive 2009/103/EC* relates to insurance against civil liability in respect of the use of motor vehicles, and the enforcement of the obligation to insure against such liability. This directive enforces all vehicles in the EU to be insured against third party liability and establishes minimum thresholds for personal injury and property damage coverage. In view of the approaching vehicle autonomy, an insurance on manufacturers' liabilities may be required. On the other hand, *Directive 85/374/EEC* applies to the liability for defective products. It considers that manufacturers can be held liable for any damage caused by a defect in their product. In case of an accident, either the driver or the manufacturer or both of them may be considered liable by a judge, depending on the exact circumstances in which it takes place. The concept of 'strict liability' appears, meaning liability in case of no fault by any party. It gives a legal basis for those situations where no one is held liable, neither the driver nor the manufacturer, so that traffic victims are compensated. The liability issue raises important concerns. The use of Event Data Recorders (EDR) to determine the exact circumstances of an accident and the deriving liabilities is being taken into consideration. As EDRs would be fitted into the vehicle during its production, they would be covered in the *Directive 2007/46/EC* on vehicle approval. Last, concerning liability in the processing of personal data, the *Directive 95/46/EC* on data protection and the proposal of a *General Data Protection Regulation* provide a framework. Article 77 of the regulation sets out the right to compensation and liability. It builds on Article 23 of *Directive 95/46/EC*, extends this right to damages caused by processors and clarifies the liability of joint controllers and joint processors. As a whole, liability is highly important in IoT technologies and the Commission is currently working on an FFD initiative to address these aspects, among others such as non-personal 'data ownership', interoperability, (re)usability and access to data. Free flow of personal data is covered in *Directive 95/46/EC*. In conclusion, it seems clear that there is a need to adapt current liability laws to the approaching automated driving technologies, with an eye to a European harmonisation on liability.

### **3.7.4 Data protection, data privacy, data security and Intelligent Transport Systems (ITS)**

In terms of connectivity, *Directive 95/46/EC* on personal data and *Directive 2002/58/EC* on privacy in electronic communications apply. The increasing amount of data generated by automated and connected vehicles will need to comply with data protection rules as far as personal data processing is concerned. These directives provide a framework, ensuring the protection of personal data and privacy as well as that its processing is for lawful, legitimate and specific purposes. Individuals should be informed about the personal data being collected, including inter alia who is collecting it and the purposes of data processing. Manufacturers and insurance companies are interested in accessing the data which is being gathered in the vehicle. The FFD initiative of the Commission in the framework of the Digital Single Market is completing a European data framework which allows to develop the data economy in compliance with data protection and data security. As part of the Digital Single Market strategy, the EU data protection laws are undergoing a reform which will end the silos of national data protection laws implemented under *Directive 95/46/EC*. This new *General Data Protection Regulation (GDPR)* will supersede *Directive 95/46/EC* and will enable to have one single data protection law applicable across the EU, instead of different national data protection laws, which will facilitate the stakeholders' compliance with data protection legislation. As part of the Digital Single Market, *Directive 2002/58/EC* (called "ePrivacy Directive") is being reviewed in order to keep pace with technological advancements in the last years and provide a high level of privacy protection for users of electronic communications services as well as a level playing field for all market players.

The Article 29 Data Protection Working Party <sup>(20)</sup>, composed of representatives from all EU Data Protection Authorities, the European Data Protection Supervisor (EDPS) and the European Commission, was set up under the *Directive 95/46/EC*. It acts as an independent

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<sup>(20)</sup> See European Commission site on Article 29 Data protection Working Party [http://ec.europa.eu/newsroom/just/item-detail.cfm?item\\_id=50083](http://ec.europa.eu/newsroom/just/item-detail.cfm?item_id=50083), last accessed 10 April 2017.

European advisory body on data protection and privacy. The Working Party has adopted its own rules of procedure and its tasks are laid down in Article 30 of the *Directive 95/46/EC* and Article 15 of the *Directive 2002/58/EC*. In 2014, the Article 29 Data Protection Working Party published an Opinion concerning the Internet of Things (Article 29 Data protection Working Party, 2014), where it states that smart transport or machine to machine developments can be covered by the principles and recommendations which are part of the Opinion, even if they are not specifically dealt with in it. When it comes to the collection of non-personal data, there is the need to regulate how this data is shared. At the moment, the only regulation in this regard is *Regulation (EC) 715/2007* on the access to repair and maintenance information. The FFD initiative will also tackle the access to non-personal data.

The European Automobile Manufacturers Association (ACEA) has agreed on a set of principles of data protection in relation to connected vehicles and services put on the market in the EU (ACEA, 2015). These principles supplement existing laws and regulations governing personal data protection and privacy in the EU, both at national and at EU level. The principles are: "1. We are transparent; 2. We give customers choice; 3. We always take data protection into account; 4. We maintain data security; 5. We process personal data in a proportionate manner." As third parties can access and use sensitive driver and driving data, legislation seems necessary to protect personal privacy of consumers in connected vehicles.

The *UN Regulation No. 116* concerning the protection of motor vehicles against unauthorised use requires that new cars have a mechanical anti-theft device to prevent unauthorised uses of the vehicle. Cybersecurity issues also need to be adequately addressed and it remains to be decided if additional regulation in this regard is needed. The Network and Information Security Directive (NIS) (European Commission, 2015f) will have an impact on cloud services that may be associated with smart car components.

The European Commission took a major step towards the deployment and use of Intelligent Transport Systems (ITS) in road transport on 16 December 2008 by adopting an *Action Plan*. The Action Plan suggested a number of targeted measures (such as travel and traffic information systems, the eCall emergency system and intelligent truck parking) and included the proposal for a Directive. In 2010 a legal framework for ITS was adopted, namely the *ITS Directive (2010/40/EU)*, with the aim of accelerating ITS deployment across Europe. This Directive is an important instrument for the coordinated implementation of ITS in Europe and aims at establishing interoperable and seamless ITS services. It reflects the challenges placed on ITS about the protection of privacy and personal data of people when travelling from one place to another. The ITS Directive empowers the Commission to adopt functional, technical, organisational and service provision specifications for the compatibility, interoperability and continuity of ITS throughout the European Union. Member States have the freedom to decide which systems to invest in. In addition, a legal framework for Cooperative ITS (C-ITS) will be necessary by 2018, probably to be included in the ITS Directive, and covering aspects such as inter alia: security, interoperability.

### **3.7.5 Passenger vehicles, commercial vehicles and ADAS**

Under the European vehicle type approval system, manufacturers can obtain approval (i.e. a Certificate of Conformity) for a new vehicle type by a national authority in charge of type approval in one EU Member State if it meets the EU technical requirements. As a consequence the manufacturer can market the vehicle EU-wide without the need for further approval tests in individual Member States. In this context, *Directive 2007/46/EC* establishes a harmonised EU-wide framework for the type approval of new vehicles and of systems, components and technical units designed for such vehicles, so as to facilitate their registration, sale and entry into service in the EU. It ensures that new vehicles and their components and separate technical units provide a high level of compliance with relevant aspects like road safety, health protection, environmental protection, energy efficiency and protection against unauthorised use. This directive refers to international

regulations, such as UN Regulations. The so called General Safety Regulation (*EC Regulation 661/2009*) amended the directive 2007/46/EC by replacing 50 EU directives by UNECE regulations on a mandatory basis. In this context, a major regulatory aspect which is currently under discussion is the introduction of technical provisions for self-steering systems (e.g. Lane Keeping Assist Systems, self-parking, Highway Autopilot). The *UN Regulation No. 79* addresses uniform provisions concerning the approval of vehicles with regard to steering equipment. It does not apply to automated steering systems and establishes a limitation of automatic steering functions to driving conditions below 10km/h. Beyond 10 km/h only corrective steering function is allowed. In addition, *UN Regulation No. 13* about braking systems is also under revision, as it caters for "Automatically Commanded Braking" but may require some examination to confirm its suitability. Another issue which could be subjected to revision under the type approval rules is related to the appropriate levels of ambient lighting at which lights may or must be switched on (*UN Regulation No. 48*). *UNECE Regulation No. 121* refers to the approval of vehicles with regard to the location and identification of hand controls, tell-tales and indicators. In this framework, it may be necessary to consider the standardisation of new tell-tales and/or acoustic warnings, such as for instance a tell-tale to inform the driver of the activation and operation of the automated driving mode or a tell-tale to warn the driver about the need to resume control of the car. Further work in this area is on-going at both national and EU levels, with consideration of harmonisation across the EU to adjust the national legislation to an EU-wide approval standard for the market deployment of AVs. This is especially critical when it comes to guaranteeing the safety of the complete vehicle's automated functionalities, rather than just considering how each individual system performs on its own and therefore addressing the interactions among different systems. Specific regulation for systems of levels 3, 4 and 5 may be necessary to facilitate their future introduction into the market.

Consequently, also the roadworthiness directives (roadworthiness package) would need to be updated to accommodate for regular inspections of this new type of vehicles. They provide a basis for checking that vehicles throughout the EU are in a roadworthy condition and meet safety standards as when they were first registered. The three directives that constitute the roadworthiness package are the following: *Directive 2014/45/EU* on periodic roadworthiness tests, *Directive 2014/47/EU* on technical roadside inspections for commercial vehicles and *Directive 2014/46/EU* on vehicle registration documents. With implementation dates ranging from 2017 to 2023, these directives will contribute to the improvement of the quality of vehicle testing and the control of cargo securing, while also including electronic safety components such as ABS or ESC in the mandatory testing. In the context of automated vehicles, roadworthiness tests may require adaptations, keeping in mind that testing procedures should be based on easy and inexpensive ways of verifying the performance of automated systems. As vehicles become more and more automated, the requirements for vehicle systems will overlap with the rules for driver behaviour (i.e. rules concerning the vehicle and rules concerning the driver). These two legislative areas will therefore need coordination.

It is worth mentioning that commercial and passenger vehicles follow parallel but asynchronous paths in terms of policy and regulation. Some key differences are that commercial vehicles drive more on highways than in urban areas, they focus a lot on fuel consumption efficiency, they are bulkier, bigger and have more operating hours than passenger vehicles. With these remarks in mind, it is expected that around 2020, automated trucks should operate under limited self-driving automation, e.g. platoons, and after 2025 it is expected that they reach full automation, i.e. SAE level 5 (see 2.2 Classification of levels of automation). Trying to draw a roadmap for the next years in commercial vehicles, one should expect more active safety Regulations and standards, more fusion between powertrain and ADAS, and the predominance of connected vehicles. The two existing regulations on LDW and AEB systems are only applicable for commercial buses and trucks. Moreover, new regulations for Blind Spot detection and speed adaptation systems are again being planned for commercial vehicles.



A 2013 study in the context of *Directive 2002/85/EC* on the installation and use of speed limitation devices for certain categories of motor vehicles) on Intelligent Speed Adaptation (ISA) devices recommends that all commercial vehicle should be equipped with ISA. Additionally, Blind spot detection for trucks (BSD-T) has been identified as having potential for improving the safety of VRUs, particularly cyclists in urban areas. In summary, all vehicles over 3.5 tons should mainly require a minimum of: collision avoidance technology on the front and sides of the vehicle, VRU blind spot detection that can filter out inanimate objects, directional warnings delivered to the driver and appropriate levels of warnings to the driver in a clear and intuitive manner with increased intensity of warning as the risk of collision increases.

Specifically, EC General Safety Regulation (*Regulation No. 661/2009*) requires the fitment of AEBS and LDW systems (LDWS) to vehicles of Categories M2, M3, N2 and N3. Separate implementing regulations apply in order to cover the detailed technical requirements of each of these systems, namely, *EU Regulation No. 347/2012* for AEBS and *EU Regulation No. 351/2012* for LDWS (Bowyer, 2012).

### **3.7.6 Infrastructure**

*Directive 2008/96/EC* covers infrastructure safety management. A set of minimum requirements for the road infrastructure (both physical and digital) could be thought to be necessary to enable the deployment and operation of automated vehicles. These could be addressing road signs and markings, digital infrastructure for connectivity, digital mapping of speed limits, among others.

### **3.7.7 Preliminary political and legal requirements for C-ART**

Building on previous subsections, the following table provides a list of preliminary political and legal requirements for a C-ART system, together with a list of remaining open questions that would require further analysis and consideration.

**Box 1.** Summary of political and legal aspects of relevance for C-ART

#### **The C-ART system would initially require:**

- That the necessary legislation to allow the circulation of highly automated vehicles is put in place, e.g. in terms of inter alia road traffic, driving licence, insurance and liability, data protection, data privacy, data security, ITS and ADAS.

#### **Key remaining open questions are:**

- Who is liable for an accident? (Car manufacturer or Driver/Car owner or the Infrastructure/authority? Who is responsible for the central controller in the case of C-ART?)

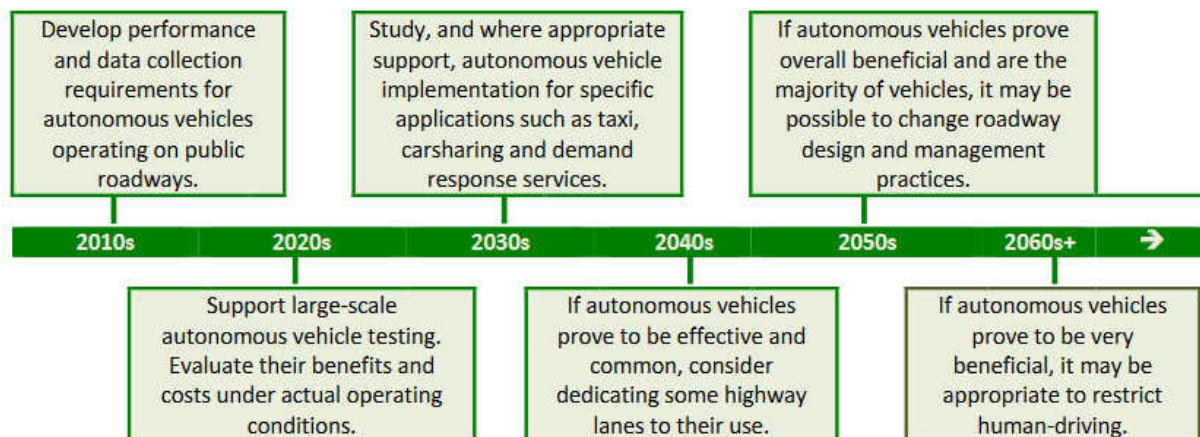
## 4 Future pathways and challenges of C-ART

Chapter 4 presents future pathways of automated and connected technologies in the short, medium, and long term under different perspectives. It also identifies where EU action may be needed.

### 4.1 Development and deployment pathways

Potential paths of development for automated and connected vehicle technologies are discussed in this section, outlining future use cases and scenarios in the short, medium and long term. These scenarios are dependent on the degree of dissemination that automated and connected vehicles will gain in the future as well as of how the move towards a model of sharing and connected mobility and use of clean vehicle technologies will actually be implemented. This is in turn depending on the technological advances, as well as progress made on regulation, data security, data privacy, liability, ethics, etc.; all of which are having an effect on public acceptance, and thus determining the broad diffusion of automated and connected vehicles. Large-scale testing and impact studies to be conducted over the next years will also have an effect on the potential pathways of automated driving, by acknowledging the actual costs and benefits emerging from the use of these advanced systems. A potential timeline for AV impacts on transport planning is presented below (see Figure 27). Several roadmaps have been elaborated in the last years. They are taken as a basis for this discussion together with evidence found in existing studies.

**Figure 27.** Timeline for AV impacts on transport planning

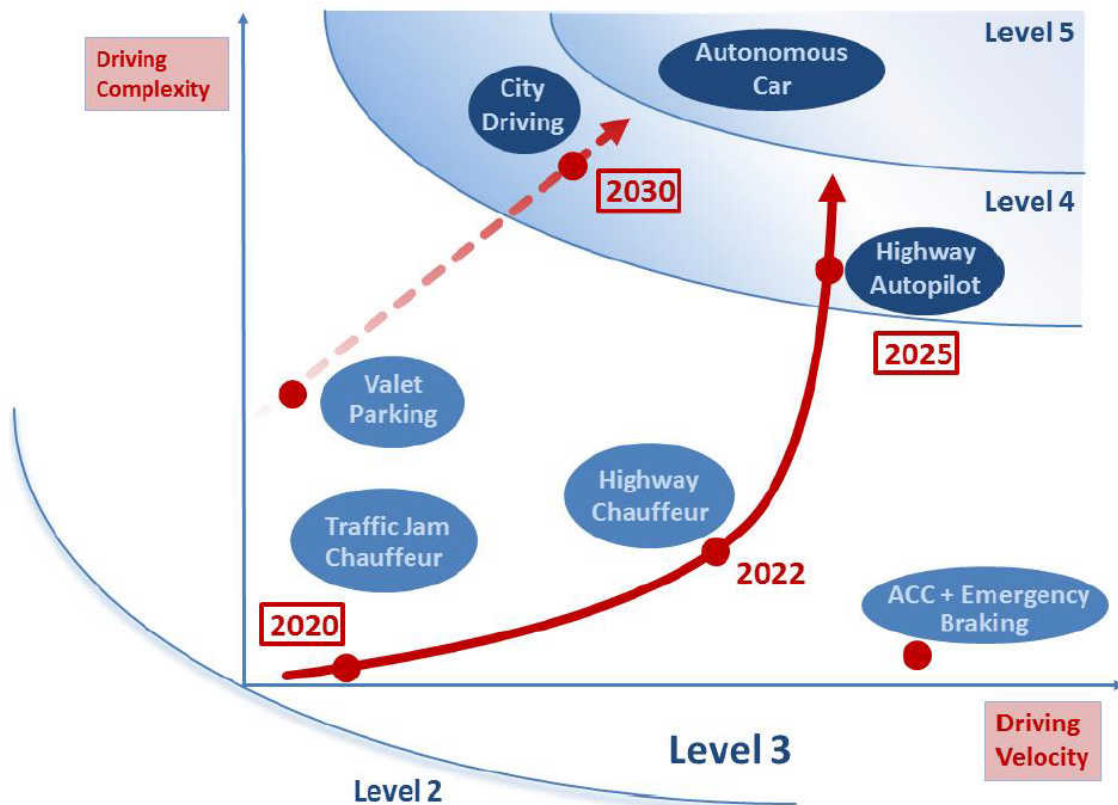


Source: Litman, 2016.

As outlined in the EpoSS European Roadmap (Dokic et al., 2015), 2 development paths can be distinguished: on the one hand, stepwise improvements from ADAS can evolve into the autonomous driving system (evolutionary scenario) and on the other hand, fundamental transformational developments based on technology transfer coming from the field of robotics (revolutionary scenario). The former focuses on steadily extending the operational domain of ADAS in more and more complex environments with higher and higher travelling speeds. The latter focuses on the protection of VRUs and on exploiting synergies with modes other than passenger cars. These two development paths for conditional and high automation systems are outlined in the next figure (Figure 28), both of them converging in level 5 full automation. They are dependent on the velocity and complexity of the driving situation: the solid path represents the evolutionary scenario whereas the dashed line represents the revolutionary scenario. Three milestones are indicated: 2020 for conditional automation level 3 systems (e.g. Traffic Jam Chauffeur), 2025 for high automation driving level 4 systems in motorways (e.g. Highway Autopilot) and 2030 for high automation driving level 4 systems in cities. Undisturbed and safe driving

in cities is considered to be the most complex task of the Level 4 automation for which full availability will be expected for 2030 in protected environments. For each of these milestones, roadmaps covering in-car technology, infrastructure, big data, system integration and validation, system design, standardisation, legal frameworks and awareness measures are created.

**Figure 28.** Development paths and milestones for levels 3 and 4 of vehicle automation until 2030



Source: Dokic et al., 2015.

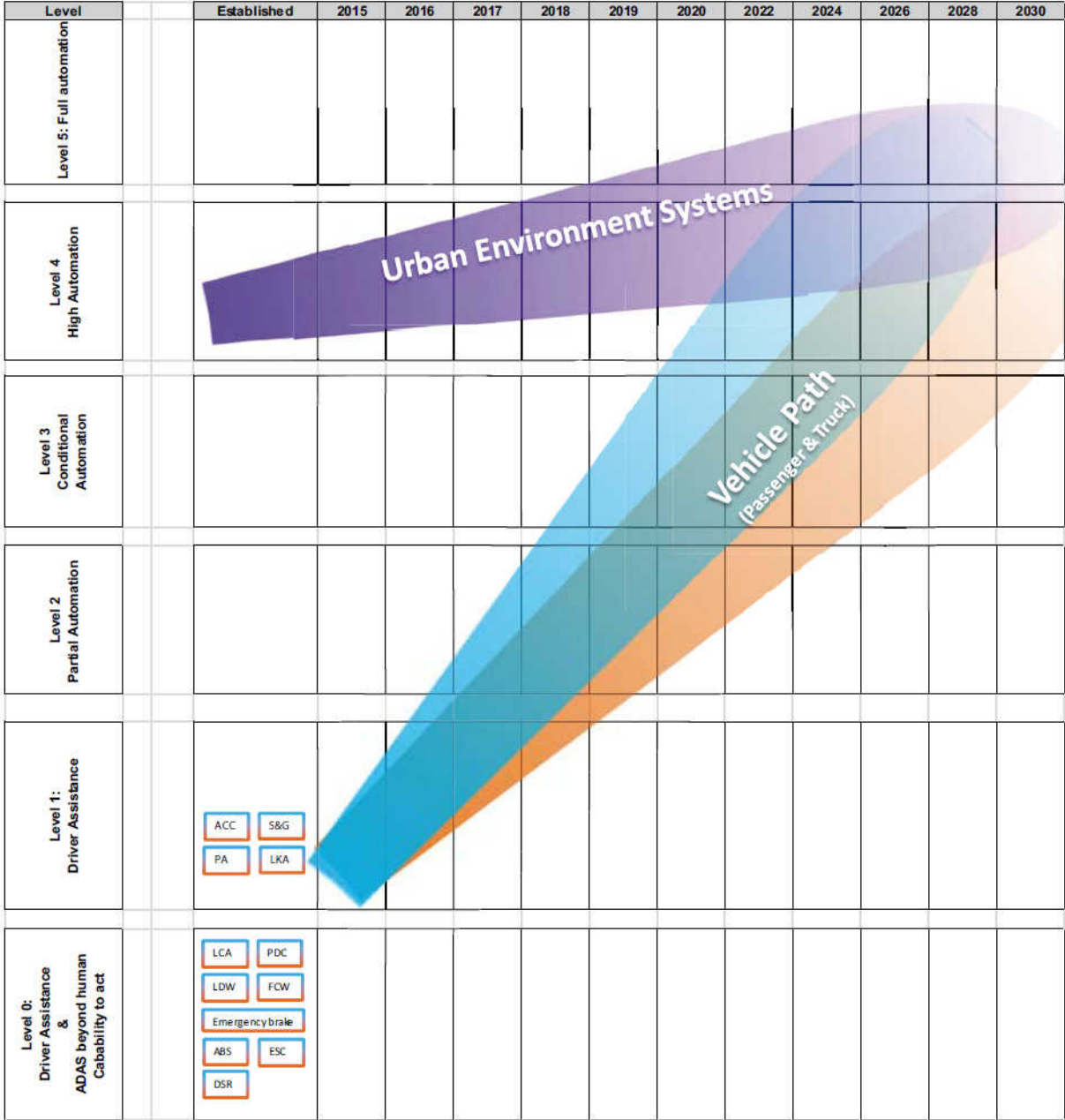
In the ERTRAC Automated Driving Roadmap (ERTRAC, 2015), three main deployment paths are considered (see Figure 29): the passenger vehicle path (see Figure 30), the commercial vehicle path (see Figure 31) and the urban environment systems path (see Figure 32). Their respective roadmaps differ, especially between the two vehicle paths and the urban environment one, with the former presenting a stepwise increase in automation levels from the current situation until 2030 whereas the latter offers a short term deployment of level 4 systems and keeps on progressing heading 2030.

In the Automated passenger cars path, two main functionalities are presented: Automated Parking Assistance (with Park Assistance Level 2 and Parking Garage Pilot Level 4) and Highway Pilot (including Traffic Jam Assist Level 2, Traffic Jam Chauffeur Level 3, Highway Chauffeur Level 3 and Highway Pilot Level 4). No concrete time estimation is given for the fully automated private vehicle level 5.

In the Automated commercial vehicles path, the following functionalities can be distinguished: Platooning (including C-ACC Platooning Level 1 and Truck Platooning Level 3) and Highway Pilot (including Traffic Jam Assist Level 2, Traffic Jam Chauffeur Level 3, Highway Chauffeur Level 3 and Highway Pilot with ad-hoc platooning Level 4). As with the automated passenger vehicles path, no concrete time estimation is given for the fully automated truck level 5.

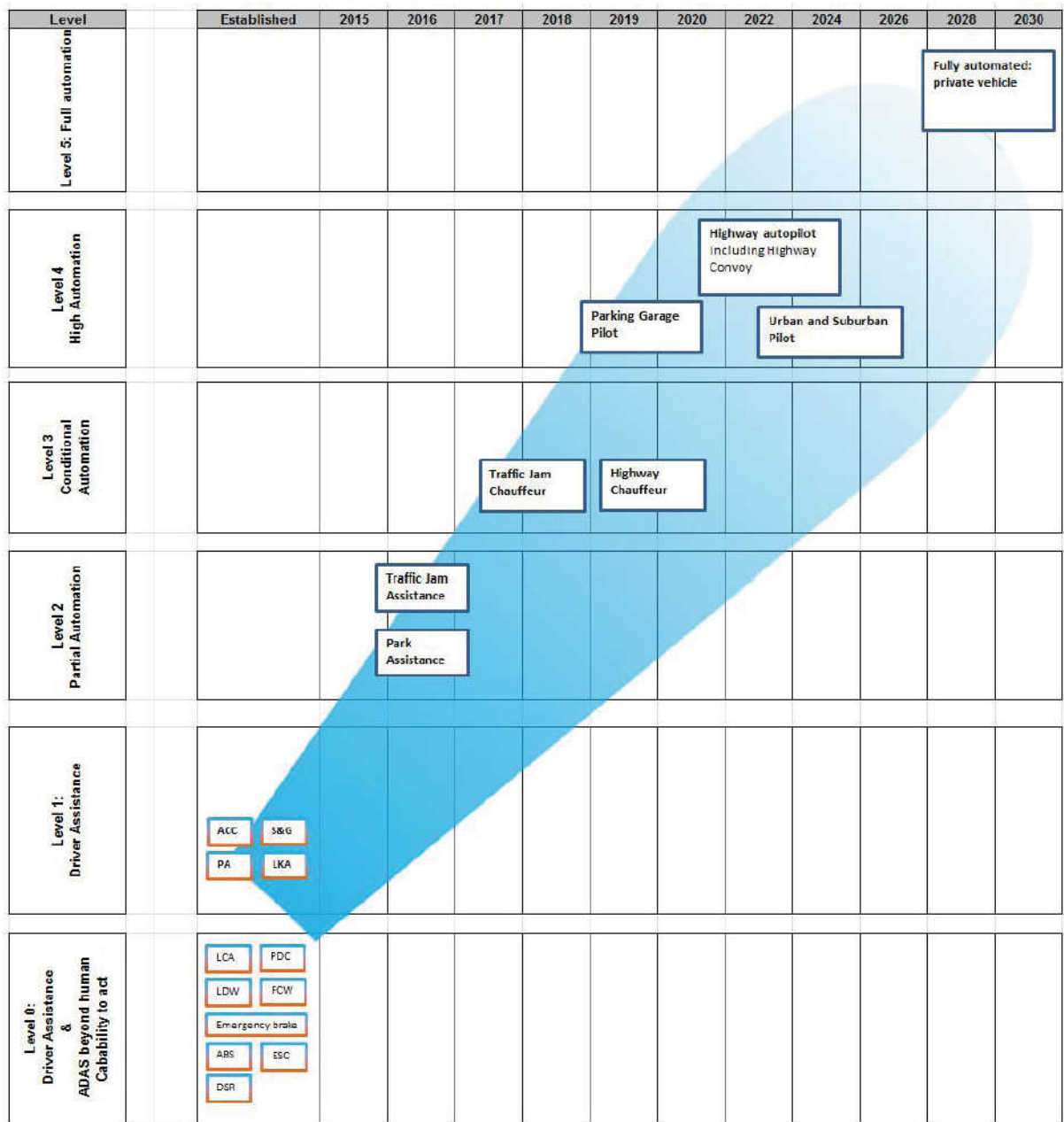
The Urban Environment systems path starts with low speed but high automation applications, already existing in some specific areas in Europe, with possibilities for going to higher and higher speeds and environments with less precise requirements. In this path, it is possible to distinguish last mile solutions on the one hand (e.g. Cybercars Gen 1 Level 4 and Gen 2 Level 4 depending on whether there is an operational speed limit or not respectively) and Automated bus or PRT on the other (which also range from Gen 1 Level 4 to Gen 2 Level 4). Again, for the automated taxi providing full automated driving to any place, no concrete time estimation is given.

**Figure 29.** The main automation deployment paths



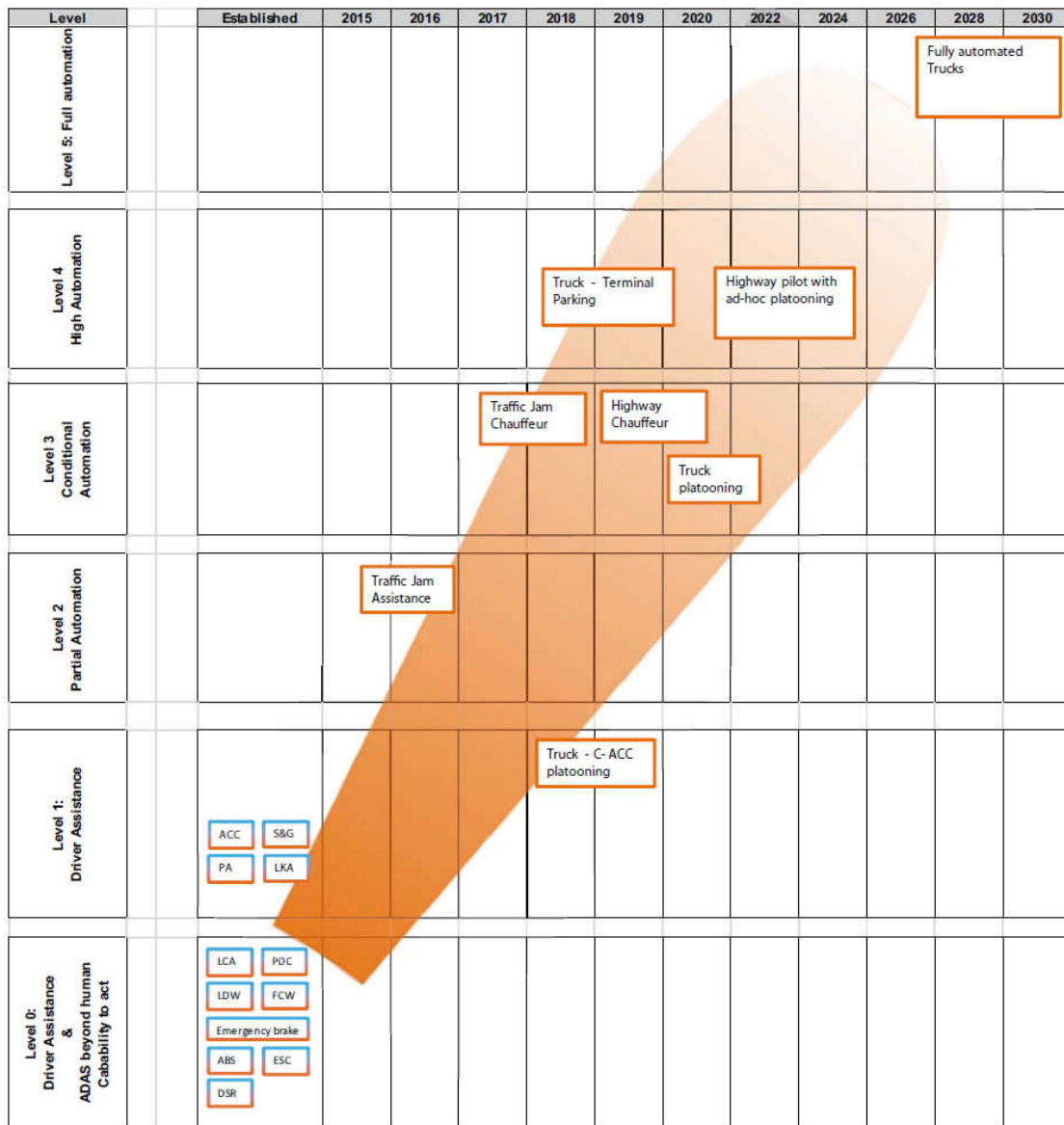
Source: ERTRAC, 2015.

**Figure 30.** Automated passenger cars deployment path



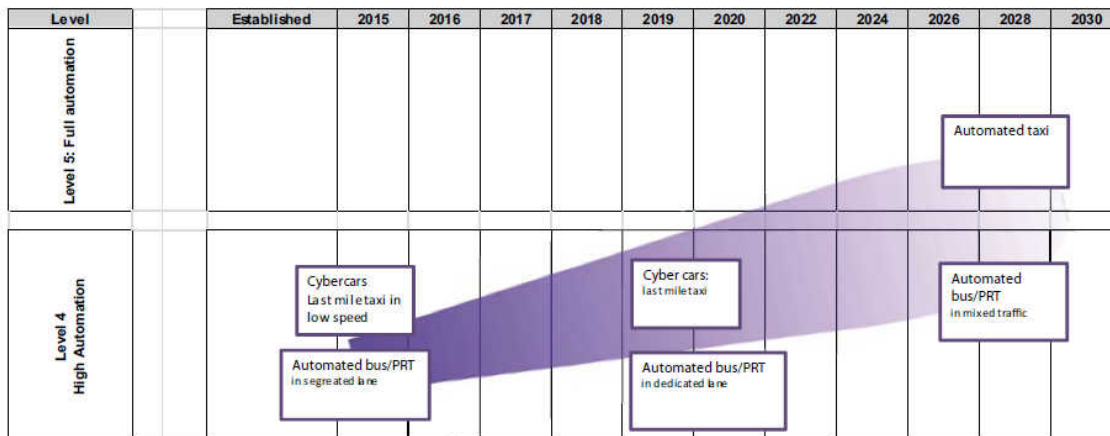
Source: ERTRAC, 2015.

**Figure 31.** Automated commercial vehicles deployment path



Source: ERTRAC, 2015.

**Figure 32.** Automated urban environment systems deployment path

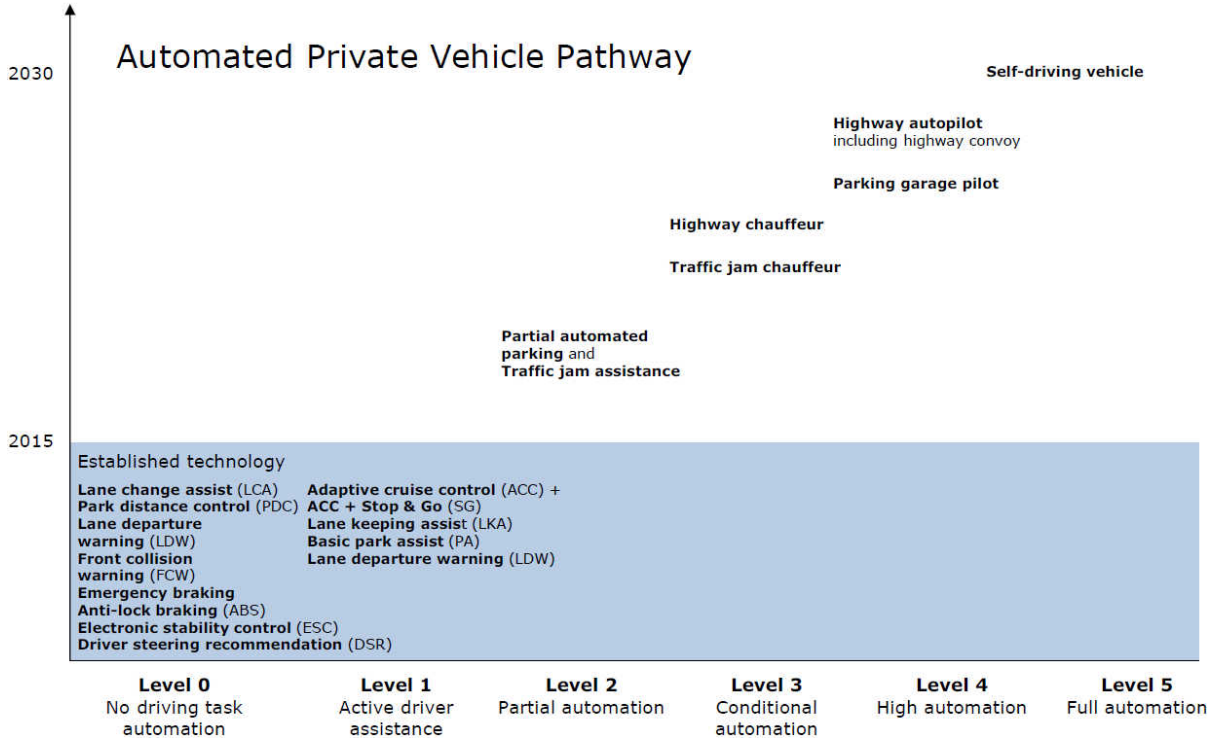


Source: ERTRAC, 2015.



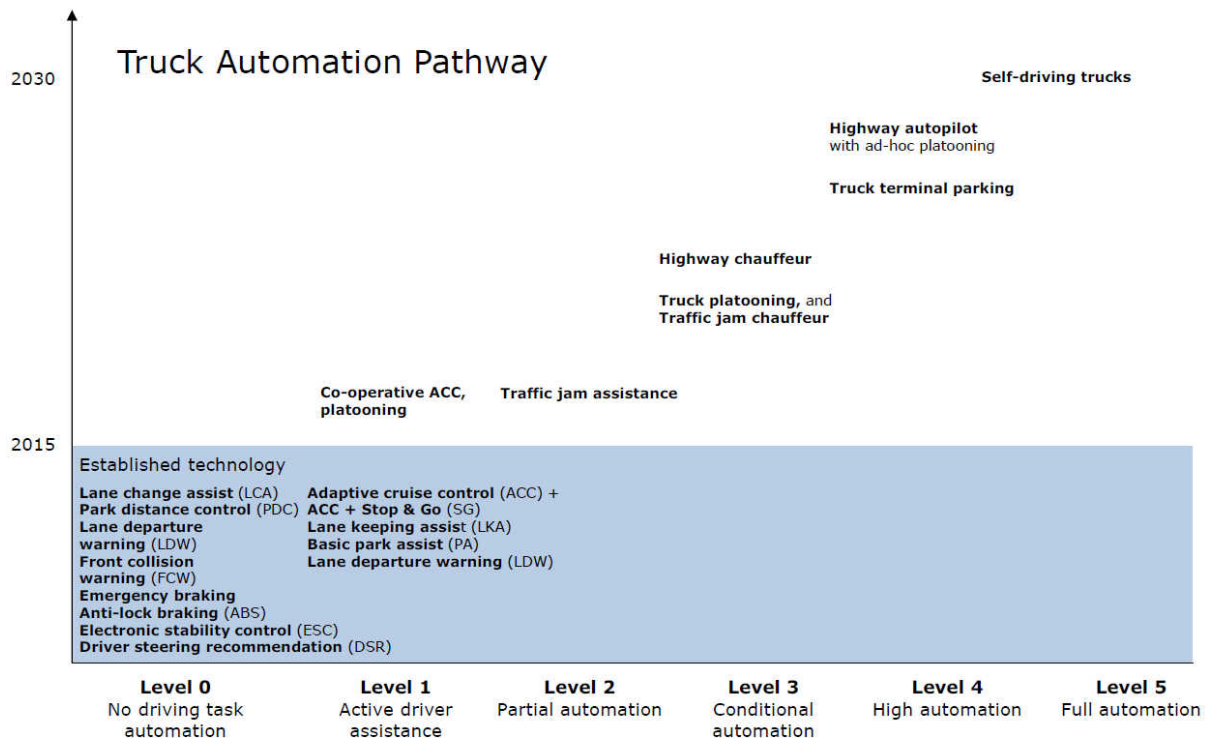
In line with the ERTRAC roadmap, a report from the OECD/ITF (OECD/ITF, 2015a) presents three deployment pathways: an automated private vehicle pathway (see Figure 33), a truck automation pathway (see Figure 34) and an urban mobility pathway (see Figure 35).

**Figure 33.** Automated private vehicle pathway from human to fully automated driving



Source: OECD/ITF, 2015a (© OECD/ITF 2015).

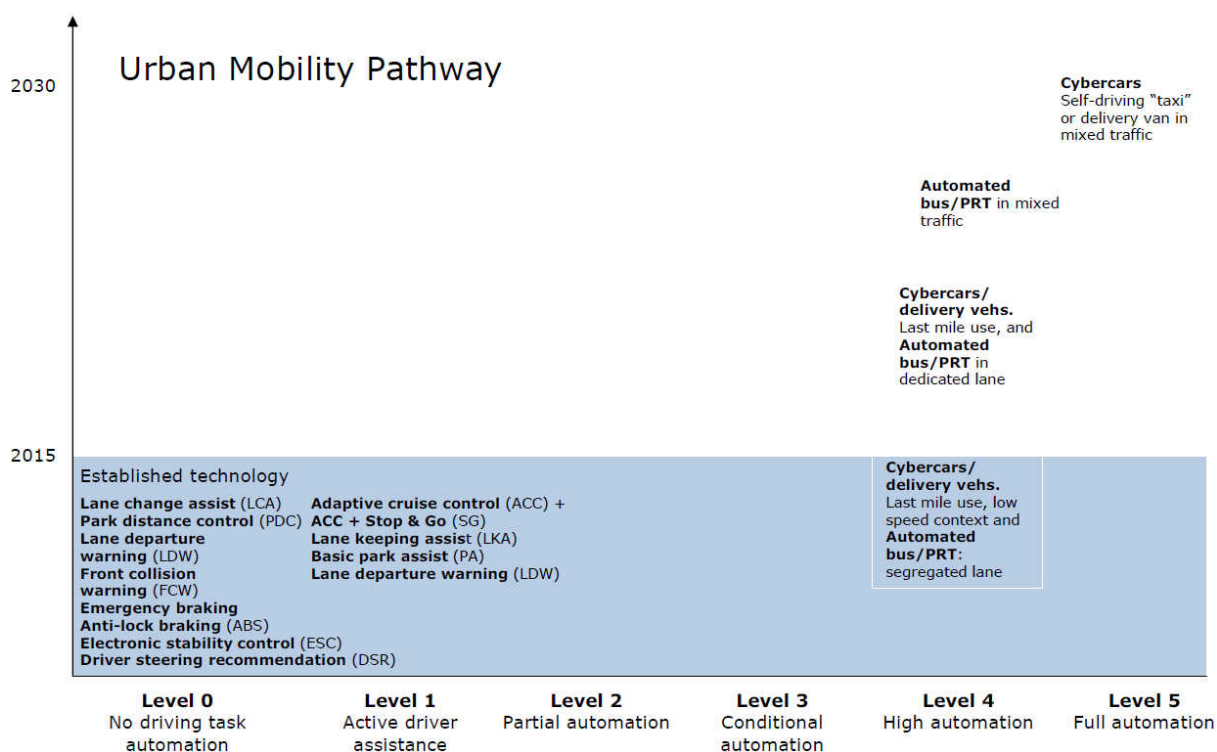
**Figure 34.** Heavy-duty truck automation pathway from human to fully automated driving



Source: OECD/ITF, 2015a (© OECD/ITF 2015).



**Figure 35.** Urban mobility pathway from human to fully automated driving



Source: OECD/ITF, 2015a (© OECD/ITF 2015).

As for the automated private vehicle scenario, there is an incremental evolution from currently available systems in levels 0 and 1 towards partial, conditional and high automation in levels 2, 3 and 4, mainly focussing on parking and highway applications. In a distant future the self-driving vehicle would be available.

In the automated heavy-duty truck scenario, there is also an incremental progress along the levels of automation. Here the focus is initially put on platooning scenarios which could provide significant benefits to the fleet operators.

The automated urban scenario initially focuses on driving at low speeds with full automation but limited areas of operation or dedicated infrastructure. Then increasing speeds and demanding less specific requirements on the infrastructure until reaching the self-driving taxi or self-driving delivery van in the long term.

The FP7 funded CityMobil2 project has provided its visions of future development of road automated transport in urban environments (Sessa et al., 2013). The first vision (Public transport) concerns innovative urban automated transport characterized by no limits or restrictions in terms of specific routes to follow, time schedules and number of stops required. The second vision (Private transport) deals, instead, with AVs that can safely chauffeur non-drivers around their communities. The third vision (Urban freight transport) focusses on innovative urban automated freight transport systems using cyber-cars for last-mile deliveries in city centres, simultaneous handling of passengers and goods in restricted areas and the transport of critical goods such as urban waste or cash to banks.

— CityMobil2 Vision 1: Innovative urban automated public transport

In 2050, a public transport system with no limits or restrictions can be imagined. Use of new technologies will make it possible to get seamless door-to-door public transport. There will not be any bus stops or time schedule. When you need to be moved from one destination to another, the vehicle will be provided to you and you will be moved according to your time schedule rather than a fixed one for everybody. Examples are cybercars, high-tech buses, PRT, advanced city vehicles and dual mode vehicles.

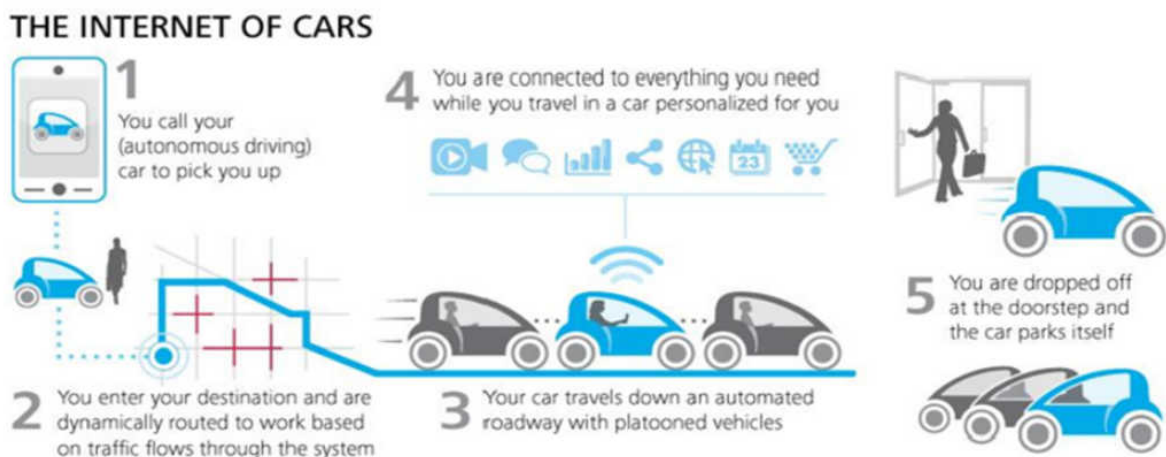
— CityMobil2 Vision 2: Self-driving cars

The most optimistic prospects from today's advocates of self-driving cars will be realized. Consumers will soon be able to purchase affordable self-driving vehicles that can safely chauffeur non-drivers around their communities, eliminating the need for conventional public transport services. Automated cars would be able to seamlessly merge into moving traffic and then exit the highway just as easily. Vehicles could be designed to optimize fuel usage at common speeds used on the road. The speed limit could be increased because there is no longer any concern with human error, and the vehicle would know how to control its situation on the road. Vehicles are also following each other consistently. The automated cars would be able to go and park themselves at a more distant location and come back when they are needed. Moreover, households will only require one car, since an automated vehicle can drop off one member and return by itself to pick up and transport other members. Rather than own one or more vehicles that sit parked most of the time, households could summon a rented vehicle as and when needed, much as they currently use a taxi. This is also linked to car-sharing possibilities.

— CityMobil2 Vision 3: Innovative urban automated freight transport

Cities can choose to use automated vehicles in their urban logistic plans and communalising the distribution of goods in specific urban areas via unloading bays or urban transport hubs, especially when Low Emission Zones (LEZ) and pedestrian zones are designated. Examples are cybercars, advanced city cars, automated vehicles on dedicated infrastructure (PRT) and high-tech lorries. The freight scenarios where the cybercars perform best are those related to "last-mile" deliveries to houses and/or small offices in city centres or suburbs, the simultaneous handling of passengers and goods in restricted areas such as hospitals, and the handling and transport of "problem goods" such as urban waste and cash to banks and post offices.

**Figure 36.** The Internet of Cars



Source: Sessa et al., 2013.

In addition, CityMobil2 projected a futuristic scenario for the cyber-mobility city of tomorrow based on a shift from privately owned individual vehicles to public individual vehicles (Utility Cars – UCs). In the cybernetic city, users will have access to UCs parked in the streets or at depots using a smartcard or similar devices containing the user profile and contract terms. In case no vehicle is available nearby, the users will be able to have access to an on-demand service using a smartphone (or other similar devices) in order to have a vehicle sent to the specified location. Vehicles will be self-driven and, therefore, users, once they have stated the desired destination, will have the opportunity to perform other activities during the trip. At destination, users will be relieved from finding a free

parking place, which is currently a cause of stress, excessive fuel consumption and traffic; they will just leave the vehicle near a parking space along the street (the vehicle will park on its own) or in the street (an automated management system of empty vehicles will move the vehicle to the nearest depot or car park). If requested, the vehicle would keep driving to pick-up the next client. An automatic self-diagnosis system of the vehicle will check the operational status of the vehicle in order to decide whether it will be able to serve another user or maintenance operations are needed (e.g. if the vehicle is electric, it will check the level of battery charge, and if low it will go automatically to the nearest depot/charging station). Time and mileage of effective use will be automatically charged on the smartcard. The management centre will have a crucial role in collecting and processing data coming from vehicles, depots and parking, and thus in allowing an efficient response to vehicle demand and a high level of service. This futuristic scenario is partially represented in Figure 36.

In line with this futuristic view, an infographic on urban development shows how AVs could transform our cities by freeing up parking space, boosting public transit, reducing the number of vehicles, making housing more affordable and completely transforming the urban cityscape (2025AD, 2016).

In the roadmap prepared by OICA (Esser, 2015) as input to the Informal Working Group on ITS and Automated Driving (IWG ITS/AD), four applications are considered resulting from a combination of different traffic environments (structured versus unstructured or complex traffic environments) and velocities (low versus high velocities). These applications are: Traffic Jam for low speeds and structure traffic environments, Parking and Manoeuvring for low speeds but complex traffic environments, Highways for high speeds and structured traffic environments and Urban and Rural Roads for high speeds but unstructured traffic environments (see Figure 37). This roadmap foresees an incremental evolution across different levels of automation. Especially relevant for the mid-term are the Traffic Jam, Highway and Parking automated functionalities. The long term scenarios deal with unstructured traffic situations with high travelling speeds (i.e. Urban and Rural Roads) (see Figure 38).

**Figure 37.** Technical complexity influences the roadmap to automated driving

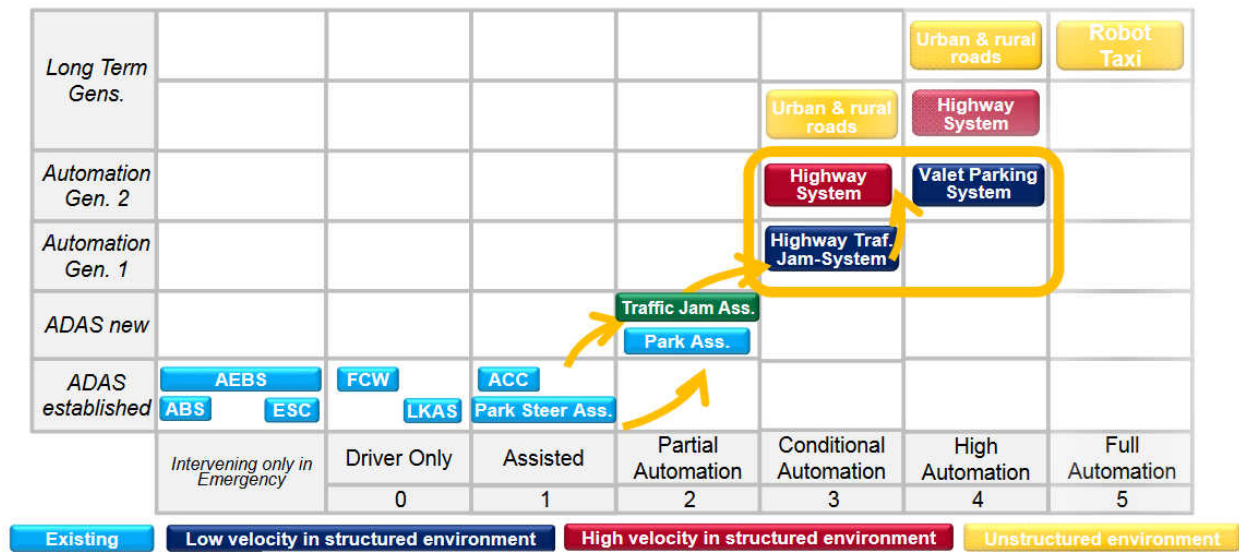
	Low Velocity	High Velocity
Structured Traffic Environment	<p><b>Traffic Jam</b></p> <p>Level 2 (limited*) already introduced Level 3 in development</p>	<p><b>Highways</b></p> <p>Level 2 (limited*) already introduced Level 3 in development</p>
Unstructured (complex) Traffic Environment	<p><b>Parking and Maneuvering</b></p> <p>Level 2 already introduced Level 4 in research/development</p>	<p><b>Urban and Rural Roads</b></p> <p>Level 2 (limited*) already introduced Level 3 in research</p>

Automated Functions like Traffic Jam-, Highway- and Parking System are currently in development and can be introduced in midterm perspective.

\* Current UN R 79 allows above 10 kph only corrective steering (lateral assistance). Therefore steering capability of today's Level 2 functions is still limited.

Source: Esser, 2015.

**Figure 38.** Roadmap of automation systems



Source: Esser, 2015.

According to research, commissioned by the European Parliament, for the TRAN Committee (Gleave et al., 2016), three potential future automation pathways are devised: one for passenger vehicles, one for freight transport and another one for urban mobility and public transport. It builds on the results and views of the OECD International Transport Forum (ITF), the European Road Transport Research Advisory Council (ERTRAC) and the European Technology Platform on Smart Systems Integration (EPoSS).

Each path follows three stages of development: short term, medium term and long term. In the short term of passenger vehicles, Level 0 and Level 1 systems will increase their market penetration (PDC, LCA, LDW, FCW, PA, LKA, ACC). Level 2 systems will be available on highways, following the amendment of the UN Regulation No. 79 in order to be also applied in situations other than parking (PA Level 2, Traffic Jam Assist). In the medium term, Level 3 systems will be implemented (Traffic Jam and Highway Chauffeurs), initially limited to motorways. These may evolve into Level 4 (Highway Pilot). Possibly, also Level 4 parking systems will be available (Valet Parking, Garage Parking Pilot, Remote Parking Pilot), at least in certain protected environments. Again, their implementation is dependent on regulations. Finally, in the long term, Level 4 systems will be expected to be applied in urban and suburban areas (e.g. as an evolution of the Highway Pilot). Fully automated vehicles Level 5 are the furthest away application of vehicle automation. Their implementation is highly dependent on regulations.

Similar systems as those presented for passenger vehicles might be applied for heavy commercial vehicles in each of the three timeframes. In the short term, Level 2 truck platooning (guarded and scheduled platooning) will be available. In the medium term, Level 3 truck platooning will be implemented, upon amendment of relevant legislations such as the European regulation regarding driving time and rest periods (Regulation (EC) 561/2006) and the digital tachograph one (Regulation (EEC) 3821/85). Following a certain market penetration of these systems, on-the-fly platooning might become possible, which means that trucks sharing parts of their trips will be able to dynamically connect to each other through the use of Platooning Service Providers. Afterwards, in the long term and upon amendment of current regulations requiring the presence of a driver inside the vehicle, Level 4 single driver platoons could be implemented. Eventually, platooning of fully automated trucks.

Concerning urban mobility and public transport, it is expected that Level 4/5 fully automated vehicles increase their implementation in the short term in industrial sites, airports, recreation parks, hospitals, resort complexes and convention centres. Applications

will range from dispersed demand areas to shared space environments. Following the necessary regulation amendments, the first implementations of Level 4 urban transport systems will start in the medium term, such as small automated passenger vehicles (e.g. shuttles) for last mile solutions at low speeds in specific dedicated areas, automated buses for mass transport in segregated lanes, fully automated podcars (PRT) with limited capacity involving Automated Guideway Transit (AGT) on their own exclusive infrastructure. As these systems prove to be safe and beneficial, applications in less protected environments are likely to emerge. Finally, in the long term, Level 4/5 systems are expected on shared infrastructure with mixed-use areas, as a complement to traditional public transport and requiring a central management system.

Four scenarios on how AVs could impact users travel patterns are described in (Litman, 2016): (i) in 2026 a man with vision-related problems purchases an AV to keep on using a private vehicle, (ii) in 2030 a woman uses automated taxi services for her occasional car trips, (iii) a couple in 2035 commutes from its extra-urban home with an AV, and (iv) in 2040 a man with alcohol problems relies on affordable used AVs to avoid impaired driving.

Three scenarios were proposed in (Trommer et al., 2016):

- *“Evolutionary automation”*: reflects an evolutionary development of AVs, with first level 4 systems on the market from 2025 and first level 5 systems from 2030, starting with the luxury segment vehicles and later on entering the smaller vehicle segments. AVs share is estimated at 17% and 11% in Germany and USA respectively in 2035. VKT increases by 2.5% and 3.5% in Germany and USA respectively. Under a legal point of view, teenagers from 14 years old are allowed to use AVs.
- *“Technology breakthrough”*: reflects a more progressive development of AVs, with first AVs on the market from 2022 onwards. Higher AVs share of 42% and 32% in Germany and USA respectively. VKT increases by 8.5% in both countries. Under a legal point of view, children over the age of 10 years old are allowed to use AVs.
- *“Rethinking (auto)mobility”*: reflects the additional use of AVs as a new mobility-on-demand concept offering car sharing and pooling services. They can constitute an 8-10% of all trips in Germany. Under a legal point of view, vehicles can move without any passengers inside.

In addition, four scenarios were described by (Wadud et al., 2016) (based on NHTSA levels of automation):

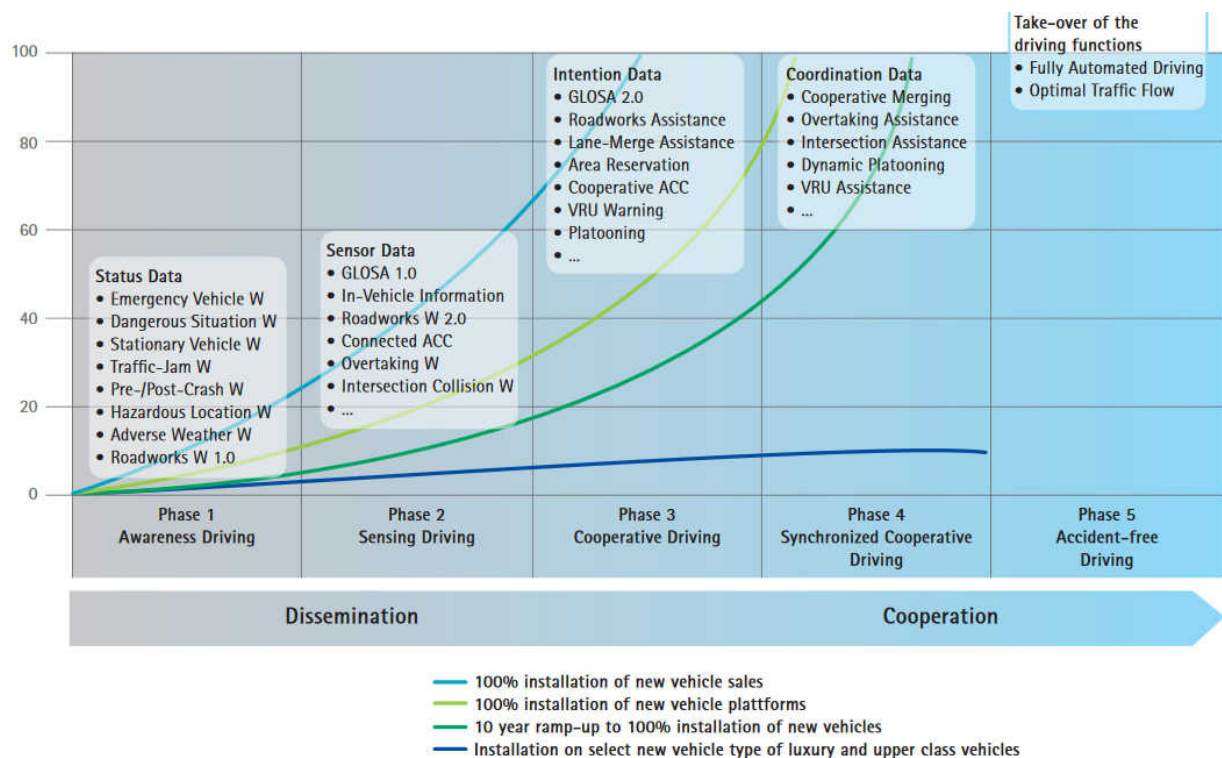
- *“Have our cake & eat it too”*: virtually all of the potential benefits of automation are realized through coordinated policy actions and cooperation with the private sector, with little downside. Level 3 automation enables much smoother traffic and vastly fewer accidents, all but eliminating congestion. Eco-driving is widely adopted, since it no longer relies on drivers modifying their behaviours. On the highways, speed limits continue to keep traffic to about 115 km/h (70 mph), and platooning is widespread. With drivers largely out of the loop and acceleration no longer important, engine power is greatly dialled back. As accidents become a rarity, vehicles become smaller and shed safety equipment. Despite the reduction in driver burden, people cannot fully disengage from driving tasks, limiting reductions in the costs of drivers’ time.
- *“Stuck in the middle at Level 2”*: many states do not allow Level 3 and 4 driving. Mid-range benefits from platooning and low-end benefits from eco-driving. Reduced accident rates, thus lowered insurance costs. More elderly people drive longer.
- *“Strong responses”*: big impacts of automation in vehicle travel, including operational improvements and many fewer accidents. Automated eco-driving and platooning exist. Passive safety measures and power become less important. However, highway speeds increase noticeably and travel demand grows as well, as a result of lower specific costs of travel. Mobility on demand services are widespread, meaning that vehicles are “right-sized” for each trip.



- “*Dystopian nightmare*”: policymakers and industrial partners promote broad adoption of level 4, with huge changes in vehicle travel. Higher speeds in highways, thus still requiring big, powerful engines. Platooning is impeded by a regulatory and liability dilemma, plus policy inaction. In cities, congestion relief from operational improvements is counterbalanced by the increase in traffic volume. Automated eco-driving fails to be implemented, given that drivers value shorter travel times over energy savings. No main changes in vehicle designs and ownership models.

From the perspective of the Car2Car Communication Consortium, the roadmap for V2X applications follows five phases (Federal Ministry for Transport, Innovation and Technology from Austria, 2016; see Figure 39). Several manufacturers have stated that they will have production vehicles with C-ITS on board by 2019 or even before this date. A first step in the implementation concerns the so called Day 1 applications, which include safety-related notifications with priority. Day 1 applications include inter alia: slow or stationary vehicle(s)/traffic jam ahead warning, road works warning, weather conditions, emergency brake light, emergency vehicle approaching, in-vehicle signage, in-vehicle speed limits, signal violation / intersection safety, traffic signal priority request by designated vehicles, Green Light Optimal Speed Advisory (GLOSA) (for more information check C-ITS Platform, 2016). These applications should be the first to be implemented in the EU by 2020. The deployment of C-ITS services will follow the “privacy by design” principle, ensuring that personal data will not be collected for further evaluation or law enforcement purposes. In Austria, C-ITS services are also planned to be offered to drivers in the subordinate network with the help of mobile networks. In a long term future, efficient automated driving could be achieved if relying on continuous coordination with traffic management.

**Figure 39.** V2X applications roadmap



Source: Federal Ministry for Transport, Innovation and Technology from Austria, 2016.

Connected and automated vehicles timelines converge towards full autonomy (GEAR 2030, 2016b; see Figure 40).

**Figure 40.** Convergence of automated and connected vehicles towards full autonomy



Source: GEAR 2030, 2016b.

As described by Etemad (Etemad, 2014), 3 main application domains can be identified for automated and connected driving: highway driving, urban driving and parking driving scenarios (parking scenarios can be classified as part of urban driving). The table below indicates the most relevant systems for each of these application domains and on the basis of levels of automation (level 0 systems beyond human capability to act are excluded) (Table 7).

**Table 7.** Examples of driving automation systems according to their main application domain and level of automation

SAE levels of automation	Main element of driving automation	Application domains and examples of driving automated systems		
		Highway	Urban	Parking
Level 0 no automation	N/A		Lane Change Assist (LCA)	
			Lane Departure Warning (LDW)	
			Forward Collision Warning (FCW)	
				Park Distance Control (PDC)



SAE levels of automation	Main element of driving automation	Application domains and examples of driving automated systems		
		Highway	Urban	Parking
<b>Level 1 driver assistance</b>	The driving automation system performs either the longitudinal or the lateral vehicle motion control subtask of the DDT	Adaptive Cruise Control (ACC)		
			ACC including stop-and-go function	
		Cooperative ACC (CACC) Platooning		
		Lane Keeping Assist (LKA)		
				Park Assist (PA)
<b>Level 2 partial automation</b>	The driving automation system performs both the longitudinal and the lateral vehicle motion control subtasks of the DDT simultaneously		Traffic Jam Assist	
				Park Assist Level 2
<b>Level 3 conditional automation</b>	The driving automation system also performs the OEDR subtask of the DDT		Traffic Jam Chauffeur	
		Highway Chauffeur		
		Truck Platooning		
<b>Level 4 high automation</b>	The driving automation system also performs DDT fallback	Highway Pilot		
		Highway Pilot with ad-hoc Platooning		
			Cyber Cars, Cyber Vans, Cyber Minibuses	
			High-Tech Buses	

SAE levels of automation	Main element of driving automation	Application domains and examples of driving automated systems		
		Highway	Urban	Parking
			Personal Rapid Transit (PRT)	
			Advanced City Cars (ACC)	
			Dual-mode Vehicles	
				Parking Garage Pilot
<b>Level 5 full automation</b>	The driving automation system offers an unlimited ODD	Fully automated cars		
		Fully automated trucks		
		Automated Taxis		

Source: Own elaborations.

In this framework, the following use cases for automated and connected driving can be distinguished:

— **Use Case 1: Highway**

- Along the road to full automation, highway driving will be supported with the following driving automation systems (in order of increasing level of automation): LDW, FCW, ACC, CACC Platooning, LKA, Highway Chauffeur, Truck Platooning, Highway Pilot and Highway Pilot with ad-hoc Platooning.

— **Use Case 2: Urban**

- Along the road to full automation, urban driving will be supported with the following driving automation systems (in order of increasing level of automation): LCA, ACC including stop-and-go function, Traffic Jam Assist, Traffic Jam Chauffeur, Cyber Cars, Cyber Vans, Cyber Minibuses, High-Tech Buses, PRT, Advanced City Cars (ACC) and Dual-mode Vehicles.

— **Use Case 3: Parking**

- Along the road to full automation, parking driving tasks will be supported with the following driving automation systems (in order of increasing level of automation): PDC, PA, Park Assist Level 2 and Parking Garage Pilot.

In conclusion, the potential deployment pathways of automated driving technologies will follow either an incremental evolution of conventional vehicles leading to higher and higher levels of automation (evolutionary approach followed by private vehicles and commercial vehicles in highways) or a radical technology-shift approach that would lead to the near-term deployment of highly automated vehicles in urban scenarios (revolutionary approach followed in urban scenarios). Thus, in this framework, 2 early applications are envisaged:

- Automated applications for highway scenarios: both cars and trucks travelling at high speeds in more controlled driving environments, i.e. with more organised vehicle flows, more uniform roads design, better maintenance, no interaction with VRUs. Possibility to use dedicated lanes. Especially relevant functionalities are: traffic jam and highway assistants for both private and commercial vehicles, and Vehicles platooning for trucks.

- Automated applications for urban scenarios: passengers and delivery shuttles travelling at low speeds on particular routes and times, including parking support and car sharing programmes.

The table below summarises the potential future pathways in consideration of three timeframes and whether it is a passenger vehicle, freight transport or urban mobility and public transport scenario, indicating the potential automated driving systems in each of them (see Table 8).

**Table 8.** Summary of future pathways and automated systems

	<b>Short term (2020)</b>	<b>Medium term (2025)</b>	<b>Long term (2030-2050)</b>	
<b>Passenger vehicle</b>	L2/3: Parking Garage Pilot Traffic Jam Chauffeur Highway Chauffeur	L4: Highway Autopilot	L4/5: Fully automated cars	EVOLUTIONARY APPROACH - SOMETHING EVERYWHERE APPROACH (slowly increasing levels of automation)
<b>Freight transport</b>	L2/3: C-ACC Platooning Truck terminal parking Traffic Jam Chauffeur Highway Chauffeur	L3/4: Highway Pilot with ad-hoc platooning	L4/5: Fully automated trucks	
<b>Urban mobility and public transport</b>	L4: Cybercars Automated bus / PRT in dedicated lane	L4: Automated bus / PRT in mixed traffic	L4/5: Fully automated taxis	REVOLUTIONARY APPROACH - EVERYTHING SOMEWHERE APPROACH (Slowly increasing operation speeds and road environments)

Source: Own elaborations.

Likewise, C-ART would follow a similar evolution by being initially deployed in highway scenarios (i.e. C-ART 2030) and later on extended to urban areas and other complex scenarios (i.e. C-ART 2050).

## **4.2 Possible need for EU action**

Three main pillars need special attention in tackling the various challenges that automated and connected vehicles will face in the next decades: technology, legislation and users. Further progress in current AV technologies is necessary, not only in terms of improving their reliability and capability to cope with the vast amount of possible scenarios involved in real driving but also in terms of reducing their price. Modifications to current legislation are necessary to allow the circulation of highly/fully automated vehicles in the roads of the EU (e.g. road traffic rules, driving license, vehicle type approval and roadworthiness testing, insurance and liability). Besides, considerations regarding public acceptance of AV technologies are essential.

In this transition to fully automated and connected vehicles, as anticipated in Chapter 3, there are specific issues that would be specifically relevant for C-ART. These are summarised below:

### **Technology requirements:**

- Highly automated driving technologies are necessary in C-ART (starting at level 3 but preferably level 4 and level 5 automation systems).
- The AV algorithms would need to be known by the C-ART system, at least up to a certain degree. This highlights the need for data sharing among relevant actors.
- V2X connectivity (mostly V2I) will be essential in C-ART as AVs need to communicate with the RTMS and could benefit of further communication possibilities.

### **Infrastructure requirements:**

- Road infrastructure would need to be equipped with RSUs to communicate with AVs and with the RTMS.
- Road infrastructure would need to be equipped with traffic monitoring devices in order to monitor the driving situation.
- Road markings and traffic signs must be clearly visible at all times (although traffic signs will also be part of the map data).
- Digital infrastructure is of paramount importance for C-ART and is required to comply with high accuracy, frequent update rates, security, data protection, etc. Having a standardised data format is essential.

### **Human factors requirements:**

- Given that C-ART would ideally work with highly automated vehicles, a dedicated in-vehicle interface that passengers can use for non-driving related activities would be convenient. In it, C-ART relevant informative messages could be included.
- C-ART could also consider using an external vehicle HMI so that pedestrians, cyclists, PTWs can stay informed about the relevant vehicle intentions.
- Probably the most relevant aspect in the context of C-ART is users' acceptance and overall users experience with the system, as it will directly influence the real system use.

### **Data requirements:**

- To ensure data privacy and data security in the data handling and sharing that C-ART will require among the different actors.

**Ethical requirements:**

- The C-ART system should not penalise any user when implementing the journey decisions, thus proper care should be given in the definition of rules and criteria governing the C-ART real time decision making process.

**Insurance and liability requirements:**

- That an appropriate legal insurance and liability framework is adopted, relying on data recordings and storage to determine who was in control of the vehicle at a given point in time.

**Political and legal requirements:**

- That the necessary legislation to allow the circulation of highly automated vehicles is put in place, e.g. in terms of inter alia road traffic, driving licence, insurance and liability, data protection, data privacy, data security, ITS and ADAS.

Consequently, to face the anticipated challenges related to C-ART, the following **main actions at EU level** are highlighted:

- Develop a coherent EU regulatory framework that allows the deployment of AVs up to full automation together with V2X connectivity, including but not limited to: traffic rules in the presence of AVs, driving licence, AVs certification, insurance and liability in AVs driving, connectivity, infrastructure, data privacy and security.
- Create a clear policy and legal framework for the data economy, enabling the free movement of data. A data sharing and access policy in conjunction with standards in data formats would be necessary.
- Consider ways to improve public acceptance through demonstration activities or awareness campaigns.
- Analyse the specific policy and legal needs in relation to the RTMS in C-ART.

Hence, specifically, it is anticipated that the following **main legal framework** would need to be adapted:

- 1949 Geneva Convention on Road Traffic
- 1968 Vienna Convention on international road traffic
- Directive 2006/126/EC on driving license
- Directive 2003/59/EC on training and initial qualifications of professional drivers
- Directive 2009/103/EC on motor insurance
- Directive 85/374/EEC on product liability
- Directive 2007/46/EC on vehicle approval
- Directive 2014/45/EU on roadworthiness
- ITS Directive 2010/40/EU
- Directive 95/46/EC on data protection
- Directive 2002/58/EC on privacy in electronic communications
- Directive 2008/96/EC on infrastructure safety management
- UN Regulation No. 116 on anti-theft devices
- UN Regulation No. 79 for steering equipment
- UN Regulation No. 131 laying down the technical requirements for the approval of Advanced Emergency Braking Systems (AEBS) fitted on trucks and coaches

Moreover, other aspects would still need clarification, namely:

**Technology-related open questions:**

- Which data are required by the AVs for a fast, safe, reliable and efficient mobility? (Devices needed? Synergies with enabling technologies like 5G or Galileo? Data requirements? Which data to be provided and maintained by road transport authorities? Which types of data will need management? Do we need to store all data? Data privacy concerns? Security concerns?)
- How to manage huge amounts of data? (Transmission problems? Latency issues? Do we consider the same order of volumes for individual AV management as for C-ART management or are these two different approaches? Which data can be shared?)
- AVs connected to a central controller? How should it optimize the transport system? (Who should govern it? Prioritization / Optimization criteria? E.g. travel time, costs, energy use, air pollution, accident risk, etc. At which level? E.g, urban, rural, national. Which are related challenges, also computationally?)
- Would AVs need to undergo an examination to obtain a driving license or can this be covered through the type approval procedure? (Testing?)
- Operational issues? (e.g. roadway types, geographical location, speed, range, lighting conditions (day and/or night), weather conditions, cross-border driving...?)
- What is the view of the industry? Is AV coordination feasible with the existing technologies? What kind of technologies are proposed?

**Infrastructure-related open questions:**

- What are the specific data requirements for C-ART?
- Could the infrastructure adopt a more active role in the management of the road transport system? (i.e. not just monitoring and communicating but actually controlling traffic)

**Human-factors-related open questions:**

- How to manage a mix of AVs and conventional vehicles? (Problems arising from their interaction? Is retrofitting of old vehicles possible?)
- Should drivers have the right and freedom to overrule the controller's decisions? (Always, on certain time periods or in specific areas?)
- What is the users' perception of AVs? (Trust? Losing joy of driving? Willingness to buy one? Willingness to pay for services? Safety, efficiency and environmental impact influencing their choice? Interaction with pedestrians?)
- Which new business models may appear? (New mobility services?)
- Need for consumer education and training?

**Data-related open questions:**

- Which data are required by the AVs for a fast, safe, reliable and efficient mobility? (Devices needed? Synergies with enabling technologies like 5G or Galileo? Data requirements? Which data to be provided and maintained by road transport authorities? Which types of data will need management? Do we need to store all data? Data privacy concerns? Security concerns?)
- How to manage huge amounts of data? (Transmission problems? Latency issues? Do we consider the same order of volumes for individual AV management as for C-ART management or are these two different approaches? Which data can be shared?)
- Could C-ART data be useful for other purposes/services?

**Ethics-related open questions:**

- Is there any specific ethical judgement of relevance for C-ART?

**Insurance and liability-related open questions:**

- Could the C-ART manager be held liable in case of an accident or damage?

**Political and legal open questions:**

- Who is liable for an accident? (Car manufacturer or Driver/Car owner or the Infrastructure/authority? Who is responsible for the central controller in the case of C-ART?)

Stakeholders' consultation will be a first step in clarifying the open questions (e.g. through informal consultations and the C-ART workshop on 12-13 June 2017). A sound preliminary definition of the C-ART system would result from this consultation exercise, updating the previous formulated requirements and concluding on the feasibility of such a solution, while at the same time identifying subsequent steps, including actions at EU level.



## 5 Conclusions

A revolution of the road transport sector lies ahead. A first set of C-ITS services will be deployed in Europe by 2019. These will be closely followed by the implementation of highly automated features in vehicles. The socio-economic impacts of these technologies can be huge. They can support the achievement of wider policy goals such as low-emission mobility, social cohesion, and increased transport efficiency as well as improved safety, competitiveness, economic growth, employment, among others. Even more broadly, automation can allow the final transition from personally owned modes of transport to the concept of mobility as a pure service, which would represent a deep societal transformation with respect to today's practice.

Although the rate at which these technologies will be spread remains unknown, it is clear that a number of factors including technology, users' acceptance and policy/regulation will play a relevant role in the transition from conventional to connected and automated driving. Further progress in current automated vehicle technologies is necessary, not only in terms of improving their reliability and capability to cope with the vast amount of possible scenarios involved in real driving but also in terms of reducing their costs. Modifications to current legislation are necessary to allow the circulation of highly/fully automated vehicles across the roads of the EU (e.g. road traffic rules, driving license, vehicle type approval and roadworthiness testing, insurance and liability). Besides, considerations regarding public acceptance of connected and automated driving technologies are essential.

Many studies have estimated a potential increase in the number of vehicle kilometres travelled as a result of these new technologies. If connected and automated vehicles lead to a greater travel demand and preference for car ownership, the positive impacts on road safety and environment may be compromised. In such a potential scenario, a totally different management of the road transport system might be required. From higher levels of coordination up to the complete control of the system might be required to ensure that the performances of the road system will not gradually deteriorate or even collapse. Public authorities are currently focusing their attention on providing the framework in which industry and operators can deploy these new technologies and systems. However, as soon as the share of vehicles with higher degrees of automation will increase, the need for different approaches to traffic monitoring and control will immediately emerge. In this study, the concept of Coordinated Automated Road Transport (C-ART) is presented as an evolution of the road transport management concept in the presence of connected and automated vehicles. C-ART would provide connected and automated vehicles with a central coordination and regulation in order to manage their access and use of the road transport system. The present report summarises the state of the current knowledge and practice in order to frame different future scenarios that can help policymakers to better plan their strategy as well as assist the academic world and industry to support the evolution by providing the tools that are necessary in the attempt to implement a fully Automated Road Transport system. Two timeframes have been considered in this analysis, for which C-ART solutions have been proposed: a short-to-medium term timeframe (2020-2030) with C-ART in certain environments and a medium-to-long term timeframe (2030-2050) when C-ART could be expanded to the entire road transport system.

A number of requirements have been derived for the proposed C-ART system, ranging from technology to infrastructure, human factors, data, ethics, insurance, liability, policy and legislation. Each of these areas highlight as well a number of open questions that would need to be further explored. Consequently, to face these anticipated challenges related to C-ART, the following main actions at EU level may be required:

- Develop a coherent EU regulatory framework that allows the deployment of AVs up to full automation together with V2X connectivity, including but not limited to: traffic rules in the presence of AVs, driving licence, AVs certification, insurance and liability in AVs driving, connectivity, infrastructure, data privacy and security.

- Create a clear policy and legal framework for the data economy, enabling the free movement of data. A data sharing and access policy in conjunction with standards in data formats would be necessary.
- Consider ways to improve public acceptance through demonstration activities or awareness campaigns.
- Analyse the specific policy and legal needs in relation to the Road Transport Management System in C-ART.

Although a lot of uncertainty exists, the background data outlined in this study suggests short and long term plausible scenarios where a C-ART solution could be beneficial. Further research is needed to deepen the understanding of such a novel approach, the potential barriers to its implementation as well as on possible design criteria. In these efforts, the oncoming stakeholders' workshop that will be held in Brussels on 12-13 June 2017 will provide the opportunity to broadly discuss these aspects with key experts from the transport sector. The adopted forward-looking and holistic approach would contribute to identify the potential challenges that this impending road transport revolution will create and thus to anticipate which actions would be required to enable the full potential of connected and automated vehicles to be deployed.

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## List of abbreviations and definitions

- ABS** Anti-lock Braking System
- ACC** Adaptive Cruise Control, the cruise control system with “automatic distance control ACC” uses a distance sensor to measure the distance and speed relative to vehicles driving ahead. The driver sets the speed and the required time gap with buttons on the multifunction steering wheel or with the steering column stalk (depending on model). The target and actual distance from following traffic can be shown as a comparison in the multifunction display. ACC including stop-and-go function: Adaptive cruise control with stop and go function includes automatic distance control (control range 0–250 km/h) and, within the limits of the system, detects a preceding vehicle. It maintains a safe distance by automatically applying the brakes and accelerating. In slow-moving traffic and congestion it governs braking and acceleration.
- It can also refer to Advanced City Cars.
- ADAS** Advanced Driver Assistance Systems, systems which are designed to support the driving task on the level of vehicle manoeuvring by providing specific information, warnings, support or actions, being relevant for immediate driver action.
- ADS** Automated Driving System, the hardware and software that are collectively capable of performing the entire Driving Dynamic Task (DDT) on a sustained basis, regardless of whether it is limited to a specific Operational Design Domain (ODD). This term is used specifically to describe a level 3, 4 or 5 driving automation system (according to SAE J3016 classification).
- AEBS** Advanced Emergency Braking Systems
- AGT** Automated Guideway Transit
- AI** Artificial Intelligence
- ART** Automated Road Transport
- AS** Active Steering
- AT** Automated Taxi
- AV** Automated Vehicle, a motor vehicle (car, truck or bus), which has technology available to assist the driver so that elements of the driving task can be transferred to a computer system. Note that Autonomous Vehicle is defined as a fully automated vehicle equipped with the technologies capable to perform all driving functions without any human intervention and is a synonym of Self-driving vehicle and Driverless vehicle.
- BSD** Blind Spot Detection
- BSD-T** Blind Spot Detection for Trucks
- CACC** Platooning
- Partially automated truck platooning in which trucks are coupled by Cooperative ACC (CACC). Engine and brake control keeps a short but safe distance to the lead vehicle. Drivers remain responsible for all other driving functions.
- CAN** Controller Area Network
- Car hailing or ride hailing**
- Car hailing or ride hailing encompasses a range of companies and services, including traditional taxis and car services. Its overarching idea is that a customer hires a driver to take them exactly where they need to go, something accomplished by hailing a taxi from the street, calling up a car service on the phone, or virtually hailing a car and driver from an app.

### *Car pooling or ride sharing*

Privately owned vehicles shared for a particular trip. In UK, the term is referred to as car sharing.

### *Car sharing*

A membership program intended to offer an alternative to car ownership under which persons or entities that become members are permitted to use vehicles from a fleet on an hourly basis. In UK, this term is referred to as car clubs.

**C-ART** Coordinated Automated Road Transport

**C-ITS** Cooperative – Intelligent Transport Systems, systems consisting of vehicles accompanied by a communication and sensor infrastructure with which the vehicles – fitted with appropriate on-board devices – are capable of communication between themselves and with the infrastructure.

### *Connected vehicle*

A motor vehicle equipped with devices to communicate with other vehicles or the infrastructure via the Internet.

**C-V2X** Cellular V2X

### *Cybercars*

These are small automated vehicles for individual or collective transport of people or goods, with the following characteristics: a) fully automated on demand transport systems that under normal operating conditions do not require human interaction; b) they can be fully autonomous or make use of information from a traffic control centre, information from the infrastructure or information from other road users; c) they are small vehicles, either for individual transport (1-4 people) or for transport of small groups (up to 20 people); d) they can either use a separated infrastructure or a shared space.

### *Directive*

A directive is a legal act of the European Union which requires member states to achieve a particular result without dictating the means of achieving that result. Thus, directives need to be transposed into national law but normally leave member states with a certain amount of flexibility as to the exact rules to be adopted.

**DNN** Deep Neural Network

### *Driving Environment*

The outside surrounding of the vehicle in on-road traffic e. g.: road markings, road signs, road infrastructure, other vehicles, objects on the road/roadside, other traffic members (pedestrians, cyclists, etc...).

### *Driving*

Activity of the primary driving task and secondary tasks associated with or supporting the primary driving task.

**DSRC** Dedicated Short Range Communication

### *Dual Mode Vehicles*

These vehicles are developed from traditional cars but are able to support both fully automatic and manual driving. The main characteristics are: a) dual mode vehicles are standard vehicles, suited to drive on public roads; b) the technology enables both fully automatic and manual driving (dual mode).

**DDT** Dynamic Driving Task, performing the lateral and the longitudinal driving task by considering the driving environment.

<i>ECU</i>	Electronic Control Unit
<i>EDPR</i>	European Data Protection Supervisor
<i>EDR</i>	Event Data Recorder
<i>EN</i>	European Norm
<i>ESC</i>	Electronic Stability Control
<i>FCW</i>	Front Collision Warning, the Front Collision Warning monitoring system uses a radar sensor to detect situations where the distance to the vehicle in front is critical and helps to reduce the vehicle's stopping distance. In dangerous situations the system alerts the driver by means of visual and acoustic signals and/or with a warning jolt of the brakes. Front Collision Warning operates independently of the adaptive cruise control or automatic distance control.
<i>FFD</i>	Free Flow of Data
<i>GDPR</i>	General Data Protection Regulation
<i>GHG</i>	Greenhouse Gas
<i>GIS</i>	Geographic Information System
<i>GLOSA</i>	Green Light Optimal Speed Advisory
<i>GNSS</i>	Global Navigation Satellite System
<i>GPS</i>	Global Positioning System
<i>GTR</i>	Global Technical Regulation

#### *High-Tech Buses*

These are buses on rubber wheels, operating more like trams than like traditional buses, with the following characteristics: a) they are vehicles for mass transport (more than 20 people); b) they use an infrastructure, which can be either exclusive for the buses or shared with other road users; c) they can use various types of automated systems, either for guidance or for driver assistance; d) they always have a driver, who can take over control of the vehicle at any time, allowing the vehicles to use the public road.

#### *Highway Chauffeur (Level 3)*

Conditional automated driving up to 130 km/h on motorways or motorway-like roads. The Highway Chauffeur operates from entrance to exit, on all lanes, including overtaking movements. The driver must deliberately activate the system, but does not have to monitor it constantly. The driver can override or switch off the system at all times. The system can request the driver to take over within a specific time, if automation reaches the system limits.

#### *Highway Pilot (Level 4)*

Automated driving up to 130 km/h on motorways or motorway-like roads from entrance to exit, on all lanes, including overtaking movements. The driver must deliberately activate the system, but does not have to monitor it constantly. The driver can override or switch off the system at all times. There are no requests from the system to the driver to take over when the system is in its normal operation area on the motorway. Depending on the deployment of vehicle-to-vehicle communication and cooperative systems, ad-hoc convoys of vehicles (platoons) could also be created.

*HMI* Human Machine Interface, it represents where the human and the machine meet. The Human-Machine Interface (HMI) consists of hardware and software that allow user inputs to be translated as signals for machines that, in turn, provide the required result to the user.

<i>IMU</i>	Inertial Measurement Unit
<i>IoT</i>	Internet of Things
<i>IoV</i>	Internet of Vehicles, IoV technology refers to dynamic mobile communication systems that communicate between vehicles and public networks using V2V (vehicle-to-vehicle), V2R (vehicle-to-road), V2H (vehicle-to-human) and V2S (vehicle-to-sensor) interactions. It enables information sharing and the gathering of information on vehicles, roads and their surrounds. Moreover, it features the processing, computing, sharing and secure release of information onto information platforms. Based on this data, the system can effectively guide and supervise vehicles, and provide abundant multimedia and mobile Internet application services.
<i>ISA</i>	Intelligent Speed Adaptation
<i>ITS</i>	Intelligent Transport Systems (ITS), advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks
<i>LCA</i>	Lane Change Assist, the system monitors the areas to the left and right of the car and up to 50 metres behind it and warns the driver of a potentially hazardous situation by means of flashing warning lights in the exterior mirrors. Also called BSD (Blind Spot Detection).
<i>LDW</i>	Lane Departure Warning, it helps to prevent accidents caused by unintentional wandering out of traffic lanes. It represents a major safety gain on motorways and major trunk roads. If there is an indication that the vehicle is about to leave the lane unintentionally, the driver is alerted visually and in some cases by a signal on the steering wheel. Also referred to as LDWS (Lane Departure Warning System).
<i>LDWS</i>	Lane Departure Warning System
<i>LEZ</i>	Low Emission Zone
<i>LKA</i>	Lane Keeping Assist, it automatically becomes active from a specific speed (normally from around 60 km/h) and upwards. The system detects the lane markings and works out the position of the vehicle. If the car starts to drift off lane, the LKA takes corrective action. If the maximum action it can take is not enough to stay in lane, or the speed falls below 60 km/h, the LKA function warns the driver, for instance with a vibration of the steering wheel. It is then for the driver to take correcting action.
<i>MANET</i>	Mobile Ad hoc Network
<i>MART</i>	Malleable Attentional Resources Theory
<i>ML</i>	Machine Learning
<i>Monitoring</i>	The activities and/or automated routines that accomplish comprehensive object and event detection, recognition, classification, and response preparation, as needed to competently perform the dynamic driving task (according to SAE J3016).
<i>NFC</i>	Near Field Communication
<i>NIS</i>	Network and Information Security
<i>OEDR</i>	Object and Event Detection and Response
<i>OTA</i>	Over The Air

*PA* Park Assist, the Park Assist function automatically steers the car into parallel and bay parking spaces, and also out of parallel parking spaces. The system assists the driver by automatically carrying out the optimum steering movements in order to reverse-park on the ideal line. The measurement of the parking space, the allocation of the starting position and the steering movements are automatically undertaken by Park Assist – all the driver has to do is operate the accelerator and the brake. This means that the driver retains control of the car at all times.

*Park Assist (Level 2)*

Partial automated parking into and out of a parking space in a public or private parking area or garage. The process is initiated remotely, e.g. via smartphone or adapted remote key. The vehicle carries out the manoeuvre by itself. The driver can be located outside of the vehicle, but has to monitor the system and can stop the parking manoeuvre if required.

*Parking Garage Pilot (Level 4)*

Highly automated parking including manoeuvring to and from parking place (driverless valet parking). In parking garages, the driver does not have to monitor the operation and may leave once the system is active. The process is initiated remotely, for instance via a smartphone or an adapted remote key.

*PDC* Park Distance Control, the Park Distance Control system assists the driver to manoeuvre into tight spaces and reduces stress by communicating distance from obstacles by means of acoustic or, depending on vehicle, optical signals.

*Platoon* Two to six cars or trucks that are closely spaced and tightly coordinated through both vehicle-to-vehicle communication and some degree of automation.

*PRT* Personal Rapid Transit, this is a transport system featuring small fully automatic vehicles for the transport of people, with the following characteristics: a) PRT operates on its own exclusive infrastructure (there is no interaction with other traffic); b) they are fully automated systems that under normal operating conditions do not require human interaction; c) they are small with a capacity usually limited to 4 to 6 persons per vehicle; d) PRT offers an on-demand service, where people are transported directly from the origin station to the destination station without stopping at intermediate stations, without changing vehicles and ideally without waiting time.

*PTW* Powered-Two Wheelers

*Regulation*

A regulation is a legal act of the European Union that becomes immediately enforceable as law in all member states simultaneously. Regulations are self-executing and do not require any implementing measures.

*RFID* Radio Frequency Identification

*RSU* Road Side Unit

*RTMS* Road Transport Management System

*SAV* Shared Autonomous Vehicle

*SDR* Software Defined Radio

*TCS* Traction Control System

*TCU* Telematics Control Unit

*Telematics*

Vehicle telematics are computer systems that automatically combine a car's data with global positioning satellite (GPS) tracking and wireless communications



technologies to enable a wide range of services and applications that aim to improve safety, security and convenience.

*TMS* Traffic Management System

*Traffic Jam Assist (Level 2)*

The function controls the forward/backward and sideways movement of the vehicle in order to follow traffic flow in low speeds below 30 km/h. The system can be seen as an extension of the ACC with stop-and-go functionality.

*Traffic Jam Chauffeur (Level 3)*

Conditional automated driving in congested conditions up to 60 km/h on motorways and motorway-like roads. The system controls the forward/backward and lateral movements of the vehicle up to the threshold speed. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can override or switch the system off at all times. There is no take over request to the driver from the system.

*Truck platooning*

This function enables platooning in a specific lane. The vehicle should be able to keep its position in the platoon with a fixed distance or fixed time difference from the front vehicle. The behaviour of the first vehicle, such as braking and steering, should be transmitted by vehicle-to-vehicle communication.

*TSR* Traffic Sign Recognition

*UC* Utility Car

*Use Case*

A driving scenario (including e. g. the driving environment, expected velocities) for which the dynamic driving task (longitudinal and lateral control) is automated. Example: Highway Chauffeur – a function that performs only on a highway, up to a maximum velocity and limited or not to certain manoeuvres (according to the system limitations and thus the level of automation).

*UX* User Experience

*VANET* Vehicular Ad Hoc Network

*VKT* Vehicle Kilometres Travelled, number of kilometres travelled in a country by all vehicles during a one year period  $VKT = \text{Number of Vehicles} \times \text{Distance Travelled}$ .

*VMT* Vehicle Miles Travelled

*V2H* Vehicle-to-Human

*V2I* Vehicle-to-Infrastructure, V2I is the wireless exchange of critical safety and operational data between vehicles and highway infrastructure.

*V2N* Vehicle-to-Network

*V2P* Vehicle-to-Pedestrian

*V2R* Vehicle-to-Road

*V2S* Vehicle-to-Sensor

*V2V* Vehicle-to-Vehicle, V2V is the wireless transmission of data between motor vehicles.

*V2X* Vehicle-to-X, V2X technologies encompass the use of wireless technologies to achieve real-time two-way communication among vehicles (V2V) and between vehicles and infrastructure (V2I).

*VRU* Vulnerable Road User

*VTT* Value of Travel Time

*Primary driving task*

Activities that the driver has to undertake while driving in navigating, manoeuvring and handling a vehicle, including steering, braking and accelerating.

*Secondary task*

Non driving activities such as communications, entertainment, information gathering, and navigation tasks which are not required to drive.

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