European Commission

# STRIA Roadmap on Connected and Automated Transport

## Road, Rail and Waterborne

**STRIA Roadmap on Connected and Automated Transport: Road, Rail and Waterborne**

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# STRIA Roadmap on Connected and Automated Transport

## *Road, Rail and Waterborne*

Directorate-General for Research and Innovation
Smart, Green and Integrated Transport

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*This report was prepared under the initiative of European Commission's Directorate-General for Research and Innovation to jointly develop a research and innovation roadmap for Connected and Automated Transport (CAT). The content of the document is mainly based on the contribution of experts of different stakeholder groups from industry, academia and national authorities. The document builds on and further develops the research and innovation strategy for CAT initially developed for the various transport modes within the Strategic Transport Research and Innovation Agenda (STRIA) first published in 2017.*

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# TABLE OF CONTENTS

# INTRODUCTION

*Connected and automated transport (CAT) is an important area of digital technology that promises a number of benefits for the individual, the society and the economy in the various sectors of transportation. In road transport, it can provide more safety, better social inclusion and higher efficiency; in railways, it enhances the performance of the overall system, including train operations, traffic management, maintenance and it creates opportunities for new mobility services; in waterborne, it can improve the safety of shipping and the efficiency of transport and logistics as well as benefit the environment; while in aviation, where it has been implemented for long time with the autopilot being the most prominent example, even higher levels of automation are aimed for, too. In general, CAT can support the competitiveness of the European transport manufacturing, telecom and IT industries on worldwide markets, and enable potentially disruptive innovation, which may lead to new services concerning the transportation of both people and freight. These possibilities benefit all transport modes, therefore, connected and automated road, rail, waterborne and air*[1] *transport are high on the agenda of the European Commission and the public authorities of the EU Member States in their planning for interoperable and multimodal mobility and transportation systems of the future.*

## Paradigm shifts

CAT implies a number of essential paradigm shifts in the different transportation modes: In road transport, e.g. where safety and efficiency have been organized for long time with the driver and other road users in charge of complying with traffic rules and traffic management, connected and automated road transport turns this concept from bottom-up to top-down: If the electronic control systems embedded in the vehicle take decisions instead of the human driver, the cognitive capabilities of an automated vehicle are determined by the performance of its perception systems, algorithms and knowledge base. Consequently, the safety concepts of connected and automated vehicles in some cases require a human driver as a fall-back option. More advanced concepts, however, do not rely on this fall-back, and rather take into account additional data and intelligence through connections with other vehicles and digital infrastructures to improve their contextual awareness. In rail, CAT shows the potential of becoming the 4th revolution of the railway system, after steam engine, electrification and high speed. In both inland and maritime waterborne transport, human errors remains the largest cause of accidents, and CAT offers the possibility to significantly reduce these risks and to enhance the management of emergencies. For example, long periods of human watchkeeping, where attention must be maintained at all times, can be replaced by automated systems detecting potential hazards, taking appropriate actions and/or alerting a human supervisor. CAT and the creation of an overarching IT

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[1] Given the great advancement of the strategic research planning in the aviation sector in CAD, it is not explicitly covered by a dedicated roadmap in this document, however it is taken into account in the chapter on cross-modal cooperation and synergies at the end.

infrastructure also have the potential to greatly decrease the environmental footprint and improve sustainability of shipping and logistics in the waterborne sector. Particularly important as the scale of shipping and freight flows increase, is that CAT promises to reduce administrative obstacles in ports, enable faster turn-around times and increases the integration between transport modes at hubs. The introduction of CAT in this sector will improve competitiveness, energy efficiency and traffic management of both inland waterways and maritime transport. Finally, in aeronautics, CAT may enable disruptive concepts such as on-demand transport of people and goods in the third dimension, by aerial drones.

## Challenges

Despite all these appealing prospects, innovation towards CAT, also poses a multitude of challenges: Generally for all modes, these include the development of technologies at hard- and software, vehicle, infrastructure, data communication and decision-making levels, as well as the validation of these technologies and the real-world testing in individual mobility, goods and passenger transportation. At the same time, the needs and expectations of other users of the transport system and the society have to be considered, particularly in terms of safety and data security, and need to be translated into technical and legal requirements.

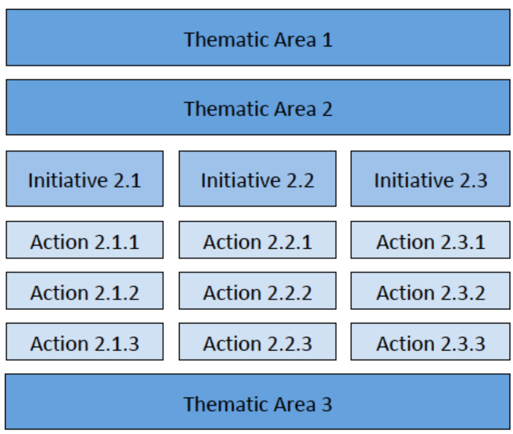
Most challenges related to CAT are specific to each mode. In road transport, the interaction of drivers, passengers and other road users with automated vehicles has to be well understood and appropriately addressed in the engineering process. Moreover, the opportunities and impacts of automation for the transport system need to be explored and proper business and operational models need to be derived, e.g. in the shared mobility domain. In railways, the long-life expectancy of rolling stock and infrastructure, the differences in legacy systems and the diversity of operational rules in various European countries may slow down the speed of deploying connected and automated systems. In waterborne, the challenges are still different: the vessels are large, with high inertia in a comparatively slow-moving environment. The market has seen an upsurge of new automated, remote control technologies in recent years but activities have mostly concerned testing, and there have been few vessel deliveries utilising these technologies so far. Secure, reliable connectivity on the high seas and ensuring coverage on inland waterways are just some of the bigger hurdles for the development. Although costs are falling, infrastructure to provide connectivity of sufficiently high quality is still expensive. A challenge for the extremely fast recent developments of CAT is concerning the safety validation and cyber-security of these technologies. Traditional validation methods, which are used in waterborne transport are based on direct human control and hardware systems and are not applicable to most CAT solutions.

Technical and non-technical innovation steps towards CAT have to be taken in sequences where they depend on each other, others have to be developed in parallel, where deployment requires proper framework conditions e.g. in the regulatory domain to be in place. If not planned comprehensively, the innovation process would slow down, resources would be wasted and Europe might miss out on the opportunities of CAT for its society and economy. In the waterborne sector, e.g., there is a wait and see attitude in the market, and the first proof of CAT concepts needed to be built to convince shipowners of the functionality of the solutions. To gain confidence in the solutions, they must first be tested in a simulated environment before larger scale physical trials. Proof of concepts based on simulated tests will therefore be important. Commercial developments are evolving quickly and at a pace which often exceeds the rate of progress in research, related policies and regulations.

## Structure of the report

This report follows the initiative of the European Commission (EC) to jointly develop a research and innovation roadmap for CAT with the involvement of representatives of the EU Member States and stakeholders from industry, academia and authorities. The document builds on and further develops the research and innovation strategy for CAT initially developed for the various transport modes within the Strategic Transport Research and Innovation Agenda (STRIA) first published in 2017[2]. For the road transport sector, it also takes into account the vision, objectives and actions for an accelerated deployment of automated mobility outlined by the EC in its Communication "On the Road to Automated Mobility"[3]

The essence of this document are roadmaps for the road, rail and waterborne transport modes explaining what has to be done to overcome the hurdles and gaps between the state of the art in CAT in Europe and the European Union's objectives. These roadmaps are structured along technical and non-technical thematic areas. They identify effective initiatives that work hand in hand to advance innovation. Each of these initiatives is supported by a sequence of actions that mainly relate to necessary research and innovation activities but also to other measures to accelerate deployment (see figure 1). These actions are put on a timeline indicating whether they are needed in the short, medium or long term, meaning until 2023, until 2030, or beyond 2030.




[2] Connected and Automated Transport. Expert Group Report, Studies and Reports, European Commission 2017.
[3] On the Road to Automated Mobility: An EU Strategy for Mobility of the Future. European Commission COM (2018) 283.

Figure 1: Structure of roadmap with thematic areas, initiatives and actions

Coherence and complementarities between initiatives and particularly between actions are highlighted and opportunities for accelerated development by agile shortcuts are shown. Ways of sharing responsibilities between the European Union, the Member States and the industry are emphasized and recommendations are derived accordingly. At the same time, potential synergies, overlaps and possible fields for cooperation between and common actions of Member States and the European Commission are emphasized. The roadmap also defines measures for a better coordination of national and multinational funding programmes in connected and automated road transport.

The document is structured into three parts, one for each mode considered, i.e. for road, rail and waterborne. Each part has chapters covering policy objectives and challenges in general and from the European Union's perspective, the state of the art in referring to technical and non-technical dimensions, the hurdles and opportunities of bridging the gap between policy objectives and state of the art, previous attempts of European Technology Platforms and funded projects, and related programs and projects of the European Union and the Member States. Afterwards the actual strategic plans are outlined: research and innovation initiatives are assessed regarding timing, responsibility and priority, planned actions are described and put into mutual relations and, concluding recommendations are made towards European Commission, Member States and industry. The three parts also contain full lists of necessary actions that had been identified by stakeholders from European Commission, Member States, industry and academia to gather and structure information on initiatives and actions.

A common, cross-modal chapter, covering technology transfer options and new opportunities arising from the move towards CAT in road, rail, and waterborne transport as well as aviation is concluding the roadmap. Abbreviations are defined in a glossary.

# PART I: ROAD TRANSPORT

## 1 Policy Objectives and Challenges

*In this chapter, first, the benefits and challenges of connected and automated road transport are introduced. Afterwards, a summary of the European Union's goals in this domain is given, as presented e.g. in the Europe on the Move policy package. And, finally, the special objectives of this roadmap and implementation plan are explained. The information given in this chapter is fundamental to the development of the strategic assessments in the course of this document.*

### *1.1 Benefits and Challenges of Connected and Automated Driving*

The potential benefits of Connected and Automated Driving (CAD)[4] for the society include primarily:

- Reduction of the number and the impacts of road accidents by supporting and gradually substituting the human driver
- Reduction of emissions due to higher energy efficiency
- Decrease of congestion by effective use of available road capacity and increased homogeneous traffic flow
- Access to mobility for all by providing inclusive individual transport means, particularly to disabled and elderly people with reduced mobility
- Increase of transport precision and comfort and more effective use of time during travelling
- Reduction of land use in cities thanks to increased use of shared vehicles and, consequently, more attractive cities for pedestrians and vulnerable road users
- Creation of new jobs and competitiveness, making Europe a world leader in fully automated and connected mobility systems and services

These potentials become particularly striking in future scenarios around full automation and connectivity of road vehicles.

The challenges related to the introduction of CAD are manifold, and are explained in much detail in the following chapters. In general, the biggest issues can be seen in:

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[4] G. Meyer, S. Beiker (Eds.), Road Vehicle Automation, Springer, Cham 2014.

- Development, validation and testing of technologies for environment perception, vehicle decision making and control, infrastructure support and data communication that ensure a safe and comfortable ride at all levels of connected and automated road transportation of people and goods considering different operational environments.

- Consideration of societal needs and expectations towards CAD, particularly in terms of road and passenger safety as well as cyber security, and their translation into technical and legal requirements, alongside its potential for increased inclusiveness and its capacity to increase vehicle occupancy rate.

- Understanding human factors in the interactions between drivers, passengers and other road users with connected and automated vehicles, and finding appropriate technical solutions in the engineering process.

- Identification of business and operational models to exploit the opportunities of CAD to provide future integrated mobility services, and to avoid the risk of increased numbers of vehicles, e.g. in terms of shared and automated mobility, and combination with public transport.

- Adaptation of the legal frameworks of road transport to CAD, regulating in a harmonized way testing methodologies and the conditions for the use of CAD on the road, and how liability issues are handled.

- Support the standardisation and harmonisation (profiling) of solutions to assure interoperability among different operational environments, road infrastructures and vehicles.

These challenges are strongly intertwined, and therefore any solutions have to build on a comprehensive strategic innovation planning process involving a multitude of stakeholders from public and private sides, coordinating tasks across European Union and Member States, and covering a number of technical and non-technical domains.

## *1.2 European Commission's Policy Objectives*

The most important objective of connected and automated driving, the radical increase of road safety referred to as "vision zero", has already been stated as a goal in the Transport White Paper of 2011.[5] It meant to move close to zero fatalities in road transport by 2050, and to halving road casualties by 2020. In view of the benefits of connected and automated driving, several other policy initiatives of the European Commission have emphasized the need to foster innovation and create the required framework conditions:

[5] Roadmap to a Single European Transport Area - Towards a Competitive and Resource Efficient Transport System, European Commission COM (2011) 144.

The C-ITS deployment platform, e.g., has helped the European Commission to establish a European Strategy on Cooperative Intelligent Transport Systems (C-ITS).[6] A security and certificate policy to secure transmissions of C-ITS messages, thereby enabling but not covering all requirements related to CAD, has been developed already. This should be the basis for further work in relation to securing CAD communication. A draft delegated regulation on C-ITS has been published on 11 January 2019 and was adopted by the European Commission on 13 March 2019.[7]

The High Level Group on Automotive Industry (GEAR 2030) in its final report noted that EU governance would be needed to take the full benefit of large scale testing research and financing programs for autonomous vehicles both at the EU and at Member State level. Moreover, the Group identified a need for data handling rules, coherent traffic and vehicle rules, and adaptations of vehicle type approval.[8]

In September 2016, the Commission launched a plan to foster the deployment of 5G infrastructures and services across the Digital Single Market by 2020.[9] The plan established a roadmap for public and private investment in 5G infrastructures in the EU. Due to its high bandwidth and low latency, 5G data communication is seen as a key enabler for safe and at the same time convenient high-degree automated driving.

In May 2017, the European Commission published the first mobility package, which includes a series of legislative and non-legislative initiatives specifically targeting road transport[10]. One of the documents prepared was the Commission Staff Working Document, which focused on the definition of a Strategic Transport Research and Innovation Agenda (STRIA).[11] This document presents a forward-looking agenda for research and innovation in transport, where connected and automated transport (CAT) is one of seven priorities.

With its third mobility package "Europe on the Move – Sustainable Mobility for Europe: Safe, Connected and Clean", [12] the European Commission in 2018 added a policy element with a strong focus on a comprehensive framework for connected and automated driving. Its ambition is "to make Europe a world leader for the deployment of connected and automated mobility making a step-change in Europe in reducing road fatalities, reducing harmful emissions from

[6] A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility. European Commission, COM (2016), 766.

[7] Commission delegated regulation supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the deployment and operational use of cooperative intelligent transport systems. European Commission C (2019), 1789.

[8] High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union, Final Report – 2017. European Commission, 2017.

[9] 5G for Europe: An Action Plan. European Commission, SWD (2016), 306.

[10] Europe on the Move: An Agenda for a Socially Fair Transition Towards Clean, Competitive and Connected Mobility for All. European Commission COM (2017) 283 final.

[11] Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility Package. European Commission, SWD (2017) 223.

[12] Europe on the Move: Sustainable Mobility for Europe: Safe, Connected and Clean. European Commission COM (2018) 293.

transport and reducing congestion".[13] In view of this goal, the European Commission follows a progressive approach based on experiences gained during testing. It focuses on use-cases which are relevant from a public policy perspective, but remains open to other new use cases in the future.

Two sets of goals have been stated in this context:

- Passenger Cars and Trucks able to autonomously handle specific situations on the motorway (automation levels 3 and 4) are expected to be available by 2020 (in particular highway chauffeur for cars and trucks, truck platooning convoys). Cars and trucks able to handle some low speed situations could be in cities by 2020, such as garbage trucks (working together with human employees) or valet parking (cars self-driving to a parking space). The capabilities of vehicles will then be further developed to satisfy increasingly complex situations (e.g. longer operating time or longer range with no driver input).

- Public Transport, vehicles able to cope with a limited number of driving situations at low speed (automation level 4) are expected to be available by 2020 (in particular urban shuttles for dedicated trips, small delivery or mobility vehicles). These will most likely still require human supervision and/or operate on a very short range. The number of situations that these vehicles will be able to handle will then increase with time (e.g. a longer operating time or longer range with no human supervision, higher speed).

### *1.3 Particular Objectives of this Roadmap on CAD*

With the communication "On the road to automated mobility: An EU strategy for mobility of the future", the European Commission proposes to develop a strategic plan of research and innovation actions and to better coordinate national and multinational funding programs on connected and automated driving. The need for a coordinated approach and priority setting for funding research, demonstration and deployment activities was also stated by the EU Member States in the Declaration of Amsterdam.[14] In this regard, the European Commission intended to develop, in close cooperation with the Member States and industry stakeholders, the roadmap at hand which includes a concrete action plan for short, medium and long-term research and innovation initiatives. Compared to the original STRIA document on CAT published in 2017,[15] this roadmap identifies initiatives and actions that are tangible and specific in terms of content, timing and responsibility. This shall also give advice for the prioritization of R&I topics for research programmes at European and national levels.

[13] On the Road to Automated Mobility: An EU Strategy for Mobility of the Future. European Commission COM (2018) 283.
[14] Declaration of Amsterdam "Cooperation in the field of connected and automated driving", signed on 14 April 2016 by transport ministers of all 28 EU member states.
[15] Connected and Automated Transport. Expert Report. Studies and Reports. European Commission 2017.

# 2 State of the Art

*This chapter first introduces the terminologies of automation levels, operational design domains and use cases that are used in the following parts of the document. Afterwards, the European state of the art in connected and automated driving is explained, referring to technical and non-technical dimensions, and building on the assessments by the involved stakeholders. Finally, Europe's competitive position in CAD is compared to the rest of the world. This shall serve as a foundation for identifying the gaps between the state of the art and the objectives outlined before, in the following chapters.*

## *2.1 Terminology*

The Society of Automotive Engineers (SAE) in 2013 released (and twice updated since) a report defining key concepts related to the increasing automation of on-road vehicles.[16] Central are six levels of driving automation: 0 (no driving automation), 1 (driver assistance), 2 (partial driving automation), 3 (conditional driving automation), 4 (high driving automation), and 5 (full driving automation). The descriptions of these levels, the related roles of the automated system and the human driver in Object and Event Detection and Response (OEDR) and Dynamic Driving Task (DDT) fallback as well as the Operational Design Domains (ODD) are summarized in figure 2.

In order to describe the limitations under which the automated driving system can be operated as intended, SAE introduced the concept of the Operational Design Domain (ODD). The term defines the boundaries of the system functionality at a certain level of automation, e.g. a particular road environment. With the concept of automation levels and ODD, relevant cases can be distinguished as follows: Level 2 automation applies to autopilot systems with permanent supervision by the driver e.g. for the ODD of an expressway that are available on the market, now. Level 3 automation would mean the next step of taking the driver out of the perception and response task but keeping him or her as a fallback solution for the dynamic driving task. Level 4 in contrast would mean there is a system fallback but in a limited ODD, while for level 5 the ODD would be unlimited. For the levels 1 to 4 the ODD by definition is limited. The boundaries are not only depending on the enabling technology of the vehicle itself but also on external factors, such as physical and digital infrastructure, traffic and weather conditions.

[16] Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems J 3016. SAE International 2018.

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

Figure 2: Levels of Automation according to SAE standard J 3016 - 2018.

A visual representation of the ODD concept is given in figure 3 where a driver leaves his destination in an automated vehicle (i.e. with Level 4 capabilities designed for highways) and driving it manually to the highway. There, at the on-ramp a transition of control (ToC) takes place and the vehicle can continue the trip in automated mode, allowing the driver to sit back and relax until the designated off-ramp is reached. There, another ToC takes place and the driver continues the trip in manual mode until the destination is reached.

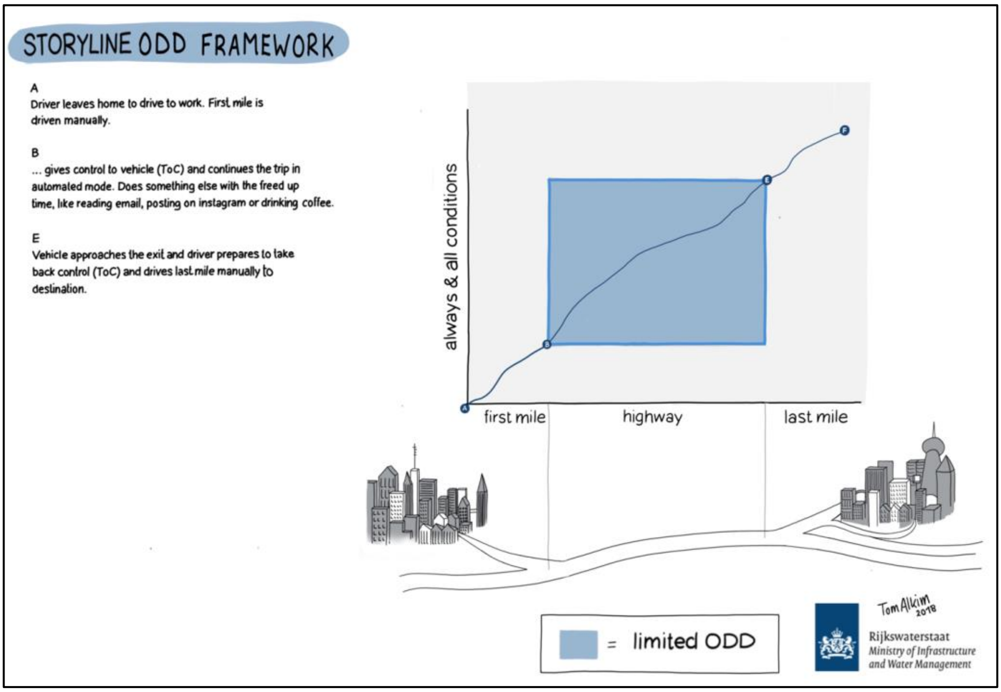


Figure 3: Visual representation of limited ODD

Unfortunately, this is a theoretic representation in most situations. In reality, a combination of factors such as the enabling technology in a vehicle (sensors, hardware, software, etc.) and many external factors, such as traffic conditions, road conditions, weather conditions, impact the shape and size of the ODD. This leads to "gaps" in the ODD (see figure 4 on th next page).

This means that there are several stakeholders to be involved to determine the specific characteristics of an ODD. A car manufacturer cannot guarantee in general that a Level 4 vehicle can always drive in Level 4 mode, but only inside the ODD. And similarly, a road operator would not be able to offer a road on which a Level 4 vehicle can be guaranteed to drive in Level 4 mode because factors outside their span of control (such as adverse weather conditions) may prevent that.

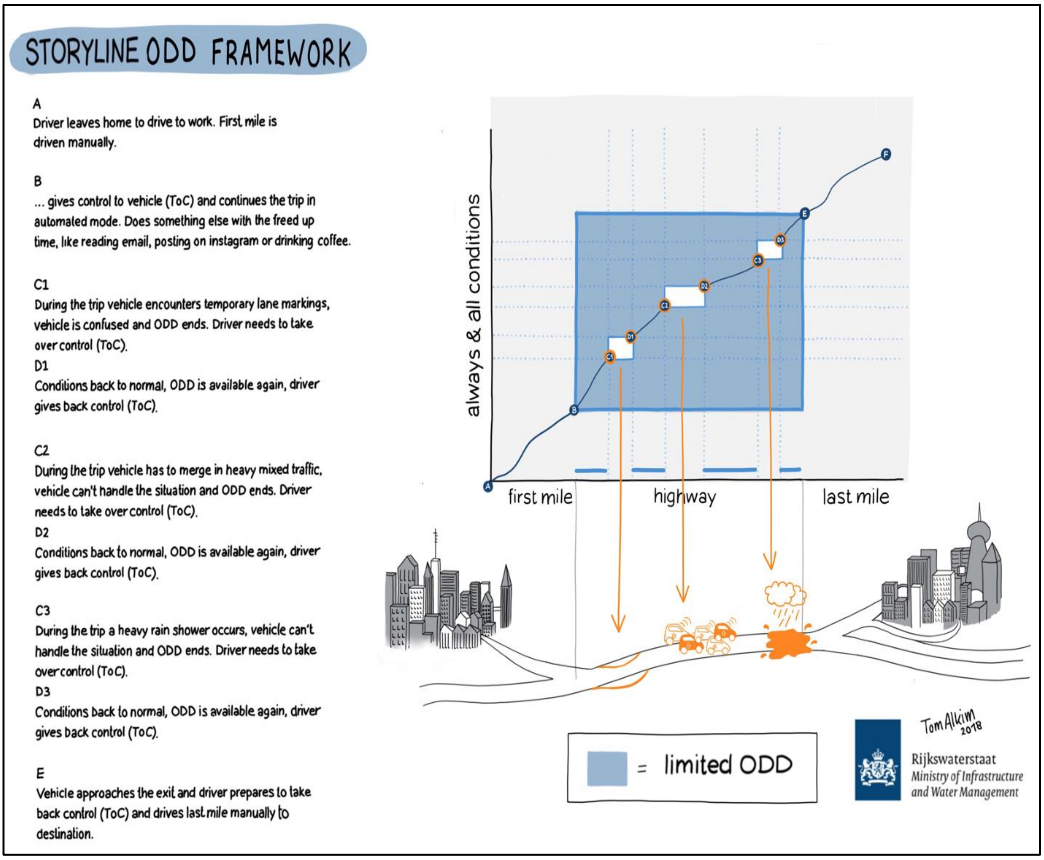


Figure 4: Visual representation of ODD in practice

## *2.2 Holistic Description of the State of the Art*

A holistic analysis of the state of the art (and, likewise, the hurdles) of connected and automated driving needs to consider technical enablers and non-technical aspects. This has successfully been achieved by the 5 layers methodology covering technical, social, economic, human factors and legal dimensions where the roles of vehicle, infrastructure and driver are distinguished at each of the layers, while clearly avoiding any preferences among those layers.[17] Without any further distinction, e.g. of automation levels, ODDs or use cases, the following general statements on the state of the art in connected and automated driving can be made referring to these layers:

Technical Layer:

From a technical point of view, connected and automated driving is based on the application of feedback-control systems consisting of components for data acquisition, perception, communication, decision making, control and

[17] D. Will, L. Eckstein, S. von Bargen, T. Taefi, R. Galbas, State of the Art Analysis for Connected and Automa-ted Driving within the SCOUT project. ITS World Congress 2017.

actuation.[18] The enabling technologies are essentially all smart systems,[19] e.g. sensor networks, maps and object classification systems, wireless data connections, microcontrollers and algorithms, electronic control systems, as well as drive by wire systems. The development of these systems has been a matter of research for decades, and they exhibit a high level of technology readiness, now: Due to advancements in environment perception and cognitive capabilities, some Level 2/3 features like traffic jam and highway chauffeur in the ODD of a motorway as well as Level 4 shuttles in a secured environment are relatively mature functionalities, and will be on the market within the next few years. Other Level 4 automated driving features, in contrast, are still considered a bigger technical challenge, particularly in complex ODDs like mixed traffic or urban driving in presence of vulnerable road users, and Level 5 requiring an unlimited ODD may be hard to achieve at all. It is now well understood that connectivity of vehicles with infrastructure based sensing as well as big data on traffic analyzed by artificial intelligence (AI) techniques, such as machine learning including deep learning, will be essential for the development of CAD under such more complex conditions. It is to be discussed, however, to what extend highly automated vehicles need to be integrated into traffic management systems for centralized control or have to remain independent in their decision-making capabilities.

Social Layer:

A number of studies have tried to assess the societal effects of CAD in terms of road safety, traffic intensity and inclusiveness: In a recent multi-stakeholder analysis of social factors of future mobility, the automated road transport has been found to meet the paradigms of a seamless, sustainable and inclusive transportation system.[20] However, no reliable information on impacts of CAD on transport, mobility patterns and land use exists. Vehicle miles travelled, and thus energy consumed for transportation may increase due to the greater convenience of automated driving, despite of the more efficient drive enabled by automation. A recent study by several National laboratories in the U.S. found that, while the energy consumption per km may decline by a factor of 1/3, the overall energy consumption may increase by a factor of three.[21] People's perception of upcoming CAD technologies is highly dependent on gender, age, country of origin and other factors.[22] A recent worldwide Deloitte study found a high degree of consumer hesitance regarding the safety of automated driving: 60-80%, depending on region.[23] Acceptance issues relate to concerns about safety, health and wellbeing of both passengers and other road users, cyber security and ethics of the use of personal data and artificial intelligence.

[18] D. Bautista et al., A review of motion planning techniques for automated vehicles. IEEE Transactions on Intelligent Transportation Systems, Nov. 2015.

[19] C. Englund et al., Enabling Technologies for Road Vehicle Automation. In: G. Meyer, S. Beiker (Eds.), Road Vehicle Automation 4. Springer, Cham 2017.

[20] Vision for 2030 Map. Mobility4EU Project, 2018.

[21] T. Stephens et al., Assessing Energy Impacts of Connected and Automated Driving at the U.S. National Level: Preliminary Bounds and Proposed Methods. In: G. Meyer, S. Beiker: Road Vehicle Automation 5. Springer, Cham 2018.

[22] Alonso M., et al., An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe – Effects of automated driving on the economy, employment and skills, EUR 29226 EN, Publications Office of the European Union, Luxembourg, 2018

[23] Global Automotive Consumer Study. Deloitte, 2017.

Economic Layer:

CAD is expected to significantly affect the competiveness of the European automotive manufacturing and transport services sectors, though business models and real business cases in support of connected and automated driving are still widely uncertain (with some exceptions such as truck platooning), and so is the relevance of services of better quality on open roads and in mixed traffic conditions, and their interaction with other existing transport modes. While mobility as a service (MaaS) concepts are currently being deployed, projects using e.g. automated on-demand shuttles in combination with those have so far only demonstrated at a small scale, with low speed and in controlled environments. Solutions are moving towards the required capabilities, and if all stakeholders agree the last generation of technologies – such as V2X functions – may soon allow to combine various vehicle types, use cases and infrastructures, and to integrate them to create new services and businesses.

Human-Factors Layer:

In terms of human factors, the shift from partial to higher automation, i.e. from SAE level 2 and below to 3, has been identified as critical, as the driver will be released from monitoring tasks but may be needed to return into responsibility as a fall back control solution within seconds. It is understood that interaction design must solve the loss of safety in such mode transition situations, and there is significant research activities around this matter, currently. There is no standardized HMI design solution so far, and acceptance problems identified may call for personalized design solutions. Also solutions are still needed for the integration of automated vehicles into mixed traffic environments with high demand for cooperative interaction between vehicles or between automated vehicle, vulnerable road users and infrastructures. These challenges apply to the vehicle side as well as to the traffic management side e.g. in Traffic Management Centers.

Legal Layer:

The Vienna Convention from 1968 is the main legal basis for the regulation of traffic in the EU and its member states.[24] Regulations concerning connected and automated driving refer to the need of a driver to maintain permanent vehicle control, the keeping of a safety distance between vehicles, technical requirements of vehicles and the steering system. The UNECE's Global Forum on Road Traffic Safety (WP.1), in 2018 adopted a non-binding legal resolution serving as a guide for the countries which are Contracting Parties to the Convention in relation to the safe deployment of highly and fully automated vehicles in road traffic.[25] With the "Declaration of Amsterdam" the transport ministers of European Member States adopted an agreement to develop automated driving technology and to put into place regulations for testing and validation of automated vehicles.[26] While different assessment methods have been worked on for automated functions, and a mix of different homologation

[24] Economic Commission for Europe, Convention on Road Traffic, 1968.
[25] UNECE, Report of the Global Forum for RoadTraffic Safety on its seventy-seventh session, 2018.
[26] Declaration of Amsterdam: Cooperation in the Field of Connected and Automated Driving, 2016.

methods for testing has been proposed, to date no common standard methodologies exist that meet the all requirements for testing, validation and certification of all levels and use cases of automated driving. The discussion on this is on-going regarding EU type vehicle approval rules as well as in the framework of the UNECE. Regarding cyber security, a general Security Policy for cooperative intelligent transportation systems (C-ITS) developed on European level now defines a trust model for the data communication for cooperative, connected and automated mobility, including legal and technical requirements,[27] however stakeholders still need to investigate their interfaces into the trusted environment defined by the security policy.

## *2.3 European Competitive Position Compared to the Rest of the World*

According to the "Scoreboard of Competitiveness of the European Transport Manu-facturing Industry" (SCORE) resulting from a EU-funded Coordination and Support Action, in terms of technological readiness of the automotive sector, "Europe has a strong competitive position, confidence in the near future and positive prospects regarding the short-term economic situation. European car manufacturers and suppliers are in a favorable position for the application of features and functionalities of new advanced driver assistance systems (ADAS). Japan seems to be at present the only country with a comparable technological capability."[28] The European leadership position in automated driving technologies is also reflected in the number of patents in the period 2010 to 2017 in this domain: The three top-ranking companies are based in Germany, thus European, and such are six out of the ten top-ranking companies.[29]

Another important factor for the European competitiveness in CAD is the strengths in traffic management and cooperative intelligent transportation systems (C-ITS) in Europe which will play a crucial role for enabling highly and fully automated driving functionalities in the future.

It should be noted though, that other regions of the world, notably the U.S., China, Korea, and –again- Japan, are challenging the European competitiveness in CAD by focusing on artificial intelligence and digital infrastructures as key technologies for the further advancement of functionalities, and by making attempts to accelerate the innovation process: A study commissioned by the European Commission recently noted the increased dynamics and intensity within the international competition and pointed to a number of practices in the CAD domain that would require adequate strategic responses by the European Union:[30]

<u>Japan</u>: Aiming at a major demonstration of connected and automated driving functionalities in the context of the 2020 Summer Olympics, Japan is focusing on the accelerated provision and installation of the required infrastructure for

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[27] European Commission, Security Policy & Governance Framework for Deployment and Operation of European Cooperative Intelligent Transport Systems (C-ITS). First release, 2017.
[28] www.transport-scoreboard.eu
[29] Deutschland hält Führungsrolle bei Patenten für autonome Autos. Institut der deutschen Wirtschaft Köln, IW-Kurzberichte 61, 2017.
[30] Towards a Single and Innovative European Transport System: International Assessment and Action Plans of the Focus Areas. European Commission, 2017.

connected and automated vehicles, cars, buses and trucks by a comprehensive strategic innovation program (SIP ADUS).[31]

United States of America: U.S.-based IT companies are promoting CAD as a case for the application of self-learning cognitive systems using artificial intelligence and the analytics of big data on traffic scenarios stored in the cloud. Not being bound to the Vienna Convention, the U.S. are also putting less legal limitations on testing and usage of CAD. The approaches are different in the various federal states, though. While some follow a "hands-off" approach, others, such as California, are establishing the necessary frameworks for testing and usage of connected and automated vehicles that are anticipating novel technology developments, but also state clear requirements. [32]

China: By initiative of the Ministry of Industry and Information Technology (MIIT), the National Development and Reform Commission (NDRC), and the Ministry of Science and Technology (MOST), China is aiming at technical leadership in "intelligent vehicles", which would mean that 50% of all new cars in China will offer some driving assistance features and low-level autonomous driving functions by 2020; this percentage is expected to rise to almost 80% in 2025.[33]

In summary, it can be stated that Europe due to a strong legacy in ADAS and C-ITS is well positioned to take a leadership position in the market on CAD in the future. However, the missing links between the vehicle technology and digital infrastructure technology domains in the innovation strategy process may weaken this potential and threaten the European position in the worldwide competition.

[31] www.sip-adus.go.jp
[32] www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing
[33] Ministry Drafts Policies to Promote Self-driving Vehicles. China Daily, 22 Jan 2018.

# 3 Hurdles and Opportunities

*This chapter summarizes the most relevant barriers for and chances of the implementation of connected and automated driving in Europe. Like the description of the state of the art in the previous chapter, technical and non-technical aspects are referred to by technology, legal, societal, economic, and human factors dimensions, while avoiding any preferences among those layers, and assessments by the involved stakeholders are closely considered. This shall serve as basis for building the plan of initiatives and actions in the following chapters.*

Technical

The technical challenges of CAD relate to vehicle and infrastructure domains as well as to communication and data processing: Future automated vehicles will consist of complex in-vehicle systems-of-systems with advanced sensors, extensive computational power and an increased dependency on software for decision making, control and actuation. These need to be automotive-graded and life-cycle proof, and have to meet cost requirements. Particularly, environment perception has to further improve as adverse weather generates challenging road conditions that are not yet well covered in the optimization and decision support of automated driving systems. While sensor technologies like camera, radar, lidar etc. have already advanced significantly, it has not yet been agreed which composition of these systems in a sensor suite would most effectively and reliably deliver the lateral, spatial and temporal resolution needed to sense dynamic environments and enable object classification to meet the safety requirements within a certain automation level and ODD. Environment perception also needs to extend towards prediction and advanced situation cognition including intention predictions of other road users, such as pedestrians and cyclists that may not comply with traffic rules or behave contrary to common sense. Using machine learning and artificial intelligence (AI) are expected to lead to significant performance increase in this regard in the future. At the same time, in-vehicle systems benefit from off-board perception systems enabled through intelligent transportation systems (ITS), such as positioning, navigation, e-horizon and dynamic maps, as well as real-time traffic information and new C-ITS services for automated driving, to enhance the in-vehicle perception system capabilities. Therefore, the in-vehicle system will reach its full potential only by being more connected to the digital road infrastructure, external networks, systems, traffic management and, e.g., the cloud for exchanging data, information and computation. This is a fundamental paradigm shift from a road vehicle as a self-aware system to a road vehicle relying on cooperation with the infrastructure, even though the appropriate split of control tasks between infrastructure and vehicle based intelligence still has to be found. Nonetheless, the vehicle-systems will eventually be updated remotely after careful tests have been undertaken before release. For this to be enabled, underlying systems as, e.g. connectivity, network and backend layer will have to fulfill their part of safety and security requirements with all constraints and implications a safety system requires.

A main challenge is to ensure functional and operational safety of such connected complex systems-of-systems, and remotely updateable vehicle systems enabling CAD. In case of the failure of subsystems or components, the vehicle must continuously remain operational, which requires advanced redundancy measures and fail-operational systems for both perception and actuation. This increasing complexity requires secure methods for remote software download and updating e.g. via block-chain. For this to happen, fail-operational safety and cyber security requirements for connected and automated in-vehicle systems need to be properly defined and agreed upon. Another main challenge is to define an ODD framework for in-vehicle, real-time decision making for safe and secure connected automated driving in relation to what is required for different automation levels, primarily suited for European traffic situations and roads. The ODDs have to link between the in-vehicle system real-time decision making process, the road and traffic situation, and traffic management guidance given, and they have to be in line with traffic rules and regulation at international, national and local levels, and provide a basis for testing, verification, validation and certification. Last, but not least, they also need to be well understood by and predictable for other road users, including e.g. pedestrians and cyclists.

In terms of infrastructures, the requirements for CAD have been understood for first applications so far, but not agreed further. Thus, a thorough understanding has to start from a discussion involving multiple stakeholders, including OEMs and infrastructure managers for the needs towards testing environments and full-scale operation of CAD. In this regard, further research is needed on the functionality and interoperability is required of traffic management systems, especially considering mixed environments with automated and non-automated vehicles. Eventually, a hierarchy of traffic centers operated by vehicle manufacturer, fleet operators and road operators may be needed. At the same time, the reliability, quality, coverage and security of connectivity needs to be considered.

For CAD, data is collected and stored in different formats and quality, and for different purposes and thus data collection is often not well synchronized nor organized. Privacy, liability, data ownership, security and ethics issues need to be addressed and solved before sharing and analyzing data. In combination with big traffic data, artificial intelligence (AI) techniques, play a major role in both data analytics and development of anticipatory capabilities in support of automated driving functions. The deployment of AI techniques to fulfill some of the automated driving functions, however, is currently limited mostly by embedded world constraints and by the lack of standardized validation methods and KPIs usable on an AI based function. Another limitation of the introduction of AI for automated driving is the access to training and testing data, and in particularly the access to a comprehensive set of driving scenarios is still missing.

Testing and validation of CAD functions have to be carried out under realistic and complex use cases, as driving tasks are progressively transferred from the driver to the vehicle. The potential methods are highly dependent on data and their quality and need to include the ODD and ISAD in their scope. Such CAD validation is no longer feasible without involving road operators and considering the entirety of the European road network from the beginning. A combination of virtual testing in simulations complemented by real world pilots could provide an adequate solution for time effective and efficient validation. The vehicle validation methodologies and procedures must also be versatile and adaptive to be able to cope with the introduction of new technologies (i.e. AI based control systems) throughout the whole vehicle lifecycle (i.e. including periodic software updates correcting and improving the vehicle functionalities). Moreover, the new set of crash causation mechanism likely present for CAD need to be understood, and related virtual assessment protocols for CAD user protection principles need to developed.

For commercial vehicles, a challenge will be to continue with pre-deployment activities to further advance multi-brand truck platooning in Europe. Also, innovative CAD solutions for heavy-duty freight vehicles need to be developed and demonstrated together with smaller and lighter last mile solutions for goods transport by different logistics stakeholders and road operators.

For bus applications, as for automated shuttles and future robotaxis, the challenges of automated drive systems are also manifold. They cover operations in real mixed traffic conditions, integration into traditional and automated public transport systems as well as Mobility-as-a-Service (MaaS) offers. Automation of busses and shuttles requires highly reliable and safe vehicles and changes in the operational models.

While there are many large-scale demonstration pilots of connected and automated driving systems already underway in the Member States, there is a strong need to further coordinate these pilots and to agree on a common testing agenda. Member States and all involved stakeholders are called for an even better cross-border cooperation on testing as well as an increased coordination and exchange on lessons learnt during testing on subjects of public interest. Harmonization and standardization is a crucial step in this context, but also for an uptake of the market taking into account the competition of vehicle manufacturers and the need for interoperable solutions in different ODDs.

Social

One of the main acceptance issues of CAD relates to the desire to stay in control: people hesitate to switch to public transport because they want to stay in control of their journey. Automated vehicles, however, will support the user in lower automation levels and take control from the user in the higher automation levels and thereby, may even make public transport more desirable. One of the key questions is how successful ride and car sharing is going to be in combination with automated driving in the future. Shared automated mobility will not be able to replace public transport, but may complement it with accessible and affordable last mile options, and they may prevent rebound-effects due to excessive individual usage. Large demonstration actions such as Field Operational Tests (FOT) would help to anticipate user and customer expectation and adoption of new automated driving technologies in real life, and to assess the impact on society for safe, efficient and inclusive mobility. The equity of mobility in terms of cost of travelling and accessibility has to be carefully considered.

In societal terms, it is also highly important that the work force in the European Union adapts to new and fast changing framework conditions and technological evolutions such as CAD. Education of automotive professions has to be drastically changed. At the present state of art, AVs cannot perform all the tasks required in most driving-related jobs. However, CAD will also increase competition in the lower-skills labour market, firstly, because it will make the job appealing for more people, secondly, because lower demand for drivers will make the transport sector less accessible.

Economic

The economic challenges and benefits of CAD cover value chain effects as well as market competition issues but also new economies of scale in the transport, mobility, automotive and supply industries: Shared mobility services promise to be the solution for reducing traffic congestion, with growing demands from the service-based economy. They potentially can be the main accelerator for the market penetration of automated vehicles by innovative business models and new stakeholders. While Mobility (and Delivery) as a Service concepts are currently deployed, most projects have so far only demonstrated services including automated mobility at a small scale, low speed and in controlled environment.

The biggest issue for shared automated mobility services is the lack of business models and real business cases, as well as the proof of relevance of services of better quality on open roads in mixed traffic conditions, and their interaction with other existing transport modes. Evaluating the attractiveness of new shared and automated mobility services, though, requires operation in real life conditions, in a broader environment, with bigger fleets, and integrated with high capacity public transport. It is necessary to create the conditions of collaboration and investment for a great number of stakeholders, and particularly, to involve citizens, cities and public authorities in the process. Therefore, large-scale demonstrations of integrated bundles of shared and automated mobility services are needed, to eventually allow for large-scale deployment and acceptance. Moreover there is a need to let users participate in the design of technologies and services.

It should be noted that traffic management is in place and should be usable to enable shared automated mobility services. The challenge, though, is to enter highly automated vehicles which are in a development phase to traffic management systems. These systems also need to grow not only towards variable speed limits, lane control and ramp metering, but also towards in-vehicle traffic jam warnings and individual route advises if that information is deemed as reliable, secured information. Also, automated vehicles need to be obliged to follow this information accordingly. Moreover, fleet management is in-place and is used for operators to optimize the vehicles in a fleet, through telematics services. These services are usually provided by different cloud platforms, branded together with the vehicles. However, on-going projects have not yet demonstrated the technical capacity to operate on open road with proper fleet supervision, and to ensure safety, security and operability of the automated systems and still respect existing traffic regulations and traffic management. The roles and potential responsibilities of stakeholders involved are currently ambiguous, thus withholding fast uptake of the discussion and interaction.

Human Factors

Regarding human factors, most prominently, interaction design must ensure the safe operation of SAE level 3 of CAD. This is even more important where the human role changes fundamentally from a driver to a user/passenger. Acceptance issues of ADAS and automated vehicles have been identified and need personalized design solutions. So far, no standardized Human Machine Interface (HMI) design solutions exist for the functional range in automated vehicles, e.g for safety-relevant areas such as indication of activated functions and transitions of control. Another issue to be addressed is potential motion sickness of passengers of a CAV.

Solutions are also needed for the integration of automated vehicles into mixed traffic environment with high demand for cooperative interaction between CAV and other vehicles and between automated vehicle and vulnerable road users and in all cases with the road infrastructure. Some first design solutions for external HMI of CAV are available and under discussion for standardization, but no harmonized solution exists. Also, there is too little knowledge and no solutions available yet for different cross-cultural needs and habits of other human road users such as pedestrians, bicyclists or vehicle drivers. Research also is missing for potentially different communication needs of different types of automated vehicles such as passenger cars, driverless shuttles, and trucks.

Also, workplaces for tele-operation of CAD need to be designed for smooth and safe human-machine operation. This implies that problems of transparency and situation awareness or time delay of communication between vehicle and controller are solved. Also, suitable HMI devices and lay out of workplaces need to be defined.

Legal

While steps have been taken to adapt the Vienna Convention to better reflect high levels of automation, issues remain in passenger transport legislation and liability issues. Upcoming Level 4 automation functions for passenger cars such as Urban and Suburban Pilot (Level 4) and Highway Autopilot including Highway Convoy (Level 4) are posing particular challenges that require demonstration actions to be supported by proper regulation in the Member States. Member States thus need to develop new or modify existing conventions for traffic rules and certification in view of safe operation of CAVs, considering newly developed awareness measures and covering e.g. automated functionality, the absence of a steering wheel etc. There is also a need to define consistent legal framework conditions for cross-border operations of CAV, e.g. for truck platooning. Furthermore, a EU-wide legal framework needs to be established that provides a basis for the clarification of responsibility, liability and insurance issues arising during the operation of CAD concerning damage or accidents, e.g. in car park applications.

# 4 Roadmaps and Plans

*In this chapter, the roadmap approaches and recommendations by the European Technology Platforms ERTRAC and EPoSS as well as the EU-funded Coordination and Support Actions CARTRE and SCOUT are summarized. Their findings are directly taken into account in the drafting of the action sheets for the plan at hand.*

## *4.1 ERTRAC Roadmap Automated Driving*

The Automated Driving Roadmap of the European Road Transport Research Advisory Council (ERTRAC) was originally published in 2015 and updated in 2017.[34] In this document, the challenges of connected and automated driving are described in three categories: vehicles, systems and services, and society. For vehicles, in –vehicle technology enablers, as well as production and industrialization are listed as fields requiring further research. For systems and services, human factors, connectivity, digital and physical infrastructure, big data and artificial intelligence, new mobility services, shared economy, and business models are mentioned. For society, user awareness and societal acceptance and ethics, needs for policies, regulation and European harmonization, socio-economic assessment and sustainability, as well as safety validation and roadworthiness testing are considered. Recommendations were made for the 2018 – 2020 calls for proposals of the Horizon 2020 work programs of the European Commission. An updated version of this roadmap, including the introduction of Infrastructure Support for Automated Driving (ISAD), will be published early 2019 and highlight more connectivity related topics.

## *4.2 EPoSS Roadmap Smart Systems for Automated Driving*

The European Roadmap Smart Systems for Automated Driving published by EPoSS[35] is describing the goals and challenges as well as the state of the art of automated driving topped off with international and member states developments and initiatives and completed with actual technical roadmaps. The motivations for automated driving comprise environmental, demographic, social as well as economic aspects, targeting increased road safety, traffic flow and efficiency as well as social inclusion.

Beside the goals, a number of challenges are considered in the roadmap. The technical issues of providing fail-safe and fail-operational functionality, risks in terms of use, security, ownership, evaluation and interpretation of data are highlighted, as concerns about those matters might slow down the acceptance of automated driving significantly. Further challenges listed in the roadmap include legal frameworks, liability and safety, implying questions regarding the responsibility; rebound effects concerning energy efficiency due to an increase

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[34] New Automated Driving Roadmap. European Road Transport Research Advisory Council (ERTRAC), 2017.
[35] European Roadmap Smart Systems for Automated Driving. European Technology Platform on Smart Systems Integration (EPoSS), 2015.

in individual road transport and with this increased driving are mentioned as well. Also, economic aspects of offering good quality at reasonable price, and validation as well as ethical aspects, which can be related to data security, liability and the legal frameworks are mentioned.

The actual roadmap section includes the development paths and milestones defined for 2020, with conditional automated driving arising along an evolutionary path and being available at low speed and less complex driving environments, e.g. in parking lots or in traffic jam situations on motorways; for 2025, including high and full on highways; and for 2030, describing the deployment of highly automated driving, i.e. self-driving cars, in cities. Action fields have been classified in the following categories: Technology inside car, infrastructure, big data, system integration and validation, system design, standardization, legal framework and awareness measures. For each of the action fields, a separate roadmap has been developed indicating the content and the timescale of actions in R&D, demonstration and industrialisation, particularly of smart systems, that are required to achieve the milestones set.

### *4.3 CARTRE Research Needs*

The EU-funded project Coordination of Automated Road Transport Deployment for Europe (CARTRE) was a Coordination and Support Action with the duration of two years starting from October 2016.[36] It aimed at accelerating the development and deployment of automated road transport by increasing market and policy certainties. The project objectives included the creation of a knowledge base of European research activities, the identification of research gaps and priorities and the support of Field Operational Tests (FOTs), e.g. by creating a data-sharing framework. CARTRE identified detailed research needs in a multitude of relevant technical and non-technical domains, including in-vehicle technology enablers, physical and digital infrastructure, connectivity, shared automated mobility services, human factors, user awareness, societal acceptance, ethics, safety validation and roadworthiness, big data, AI and their application, as well as socio-economic assessment and sustainability.

### *4.4 SCOUT Level 4/5 Comprehensive Roadmap*

The EU-funded Coordination and Support Action “Safe and Connected Automation of Road Transport” (SCOUT) aimed to establish a comprehensive and structured roadmap for CAD that reveals the interdependencies of technical and non-technical issues and identifies opportunities for accelerating the innovation process. The future vision for CAD had been developed within the SCOUT project in a user-centric approach with the support of various stakeholders from e.g. city governments, vehicle manufacturers and telecommunication experts. The essence of that vision consisted in level 4 and 5 automated driving in different use cases. In order to properly address the complexity of the comprehensive innovation planning process for level 4/5 CAD,

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[36] Jointly with the SCOUT project, CARTRE created the website www.connectedautomateddriving.eu and organized the 1st European Conference on Connected and Automated Driving in April 2017. The work of the CARTRE and SCOUT projects is continued in the Coordination and Support Actions ARCADE and COSMOS.

the SCOUT project developed a simplified and use case-specific roadmap template covering (a) a story map with hurdles and opportunities on the way from state of the art to future vision, (b) goals in terms of milestones on the timeline towards the vision, and (c) a plan of timely sequenced actions in the five layers back-casted from one of the milestones. The actions in the roadmap are expected to trigger each other, e.g. by an invention, customer demand, business model, user needs, product design, norm or regulation. As this helps to anticipate time sinks and risks for delays in the innovation process, opportunities for taking agile shortcuts between the layers should be incorporated into the design of the action, e.g. demonstrations, sandboxes approaches, co-creation session, and living labs. This approach was applied to five use cases of CAD, being automated on-demand shuttle, truck platooning, automated valet parking, delivery robot and traffic jam chauffeur.[37]

[37] J. Dubbert, B. Wilsch, C. Zachäus, G. Meyer, Roadmap for accelerated innovation in level 4/5 connected and automated driving. In: J. Dubbert, B. Müller, G. Meyer (eds.), Advanced Microsystems for Automotive Applications 2018 – Smart Systems for Clean, Safe and Shared Vehicles. Springer 2018.

# 5 Programs and Projects

*The purpose of this chapter is to draw the landscape of the European Union's and Member States' previous and current actions in terms of programs and projects for innovation in connected and automated driving.*

## *5.1 European Commission*

The European Union has funded research and innovation in the domain of automated driving for more than a decade. Automated driving was the subject of funding program in the European Commission's sixth and seventh research framework programs. For 2014-2020, a total budget of around EUR 300 million from the EU's framework program for research and innovation, Horizon 2020, has been allocated to support research and innovation on automated vehicles, half of which was provided through calls launched in 2016 and 2017. The focus lies on large-scale demonstration pilot projects to test highly automated driving systems for passenger cars, efficient freight transport operations and shared mobility services in urban areas. Other research priorities include user acceptance, design of a safe human-machine interface, road infrastructure to support automation and testing and validation procedures of automated driving functions.

The Commission also provides financial support to stakeholders to develop a network of pan-European 5G cross-border corridors for large-scale testing and early deployment of advanced connectivity supporting connected and automated driving. As a result of a dedicated H2020-5G PPP call with €50 million funding, three projects trialling 5G for connected and automated driving on cross-border corridors have been launched at the end of 2018. [38]

The move towards the automation of road transport has also been supported significantly by the program of the Connecting Europe Facility (CEF), which has fostered C-ITS deployment and projects to digitize road transport infrastructure with a total of EUR 443 million triggering EUR 1,173 million of total investment.[39] Large-scale deployment initiatives on the trans-European transport network were enabled in 16 Member States and 2 associated countries for interoperable vehicle-to-vehicle and vehicle-to-infrastructure communications based on Wi-Fi and 3G/4G cellular technologies.

Detailed information about the European Commission's programs and projects can be found at the Transport Research and Innovation Monitoring and Information System (TRIMIS).[40]

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[38] ec.europa.eu/digital-single-market/en/news/connected-and-automated-mobility-three-5g-corridor-trial-projects-be-launched-ict-2018-event

[39] ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/apply-funding/2018-cef-transport-call-proposals

[40] trimis.ec.europa.eu

## *5.2 EU Member States*

The EUREKA project "PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety" (PROMETHEUS) which took between 1987 and 1995 and received 749 million Euros in funding from the EUREKA member states, together with funding from the automotive sector, already covered many of the issues of automated driving that sometimes are still of concern today.

Current activities of European Member States in support of innovation for connected and automated driving can be briefly summarized according to the reports of the involved Member States representatives as follows:

Austria

A major source of research funding for connected and automated driving in Austria is the Research Program Future Mobility owned by the Federal Ministry of Transport, Innovation and Technology (BMVIT). It focuses on the search for integrated solutions designed to help build the mobility system of the future, a system that must balance social, environmental and economic needs. This integrated approach helps to create systems that contribute significantly to ensuring mobility while minimizing the negative impacts of transport. Examples of relevant current projects are test regions like ALP.Lab, the Austrian Light Vehicle Proving Region for Automated Driving [41], and DigiTrans [42]. While ALP.Lab is focusing on light vehicles, DigiTrans aims on the establishment of test region for automated and interconnected driving within the central area Austria North, taking into account the requirements of industry and infrastructure operators and focus on a user- and impact-driven realization within a sustainable operating model.

The flagship project "Digibus® Austria" pursues the goal to research and test methods, technologies and models for proofing a reliable and traffic-safe operation of automated shuttles on open roads in mixed traffic in a regional driving environment on level 3 and creating foundations for automation level 4.[43] This should enable public automated mobility systems in terms of first and last-mile scenarios.

In November 2018, the BMVIT published the new action package "Automated Mobility (2019-2022)" focusing on drones, automated cars and trucks as well as trains.[44] It became apparent that, beyond the scientific and business communities, there is considerable interest in the topic of automated mobility within the public sector, as well as among infrastructure operators and end-users. Therefore, three fields of action have been defined: transparent information, ensuring safe test as well as the implementation of regular operation and gaining and learning experience. In order to achieve the guidelines and actions mentioned above, 34 measures have been defined for the coming years. Of crucial importance is the further adaptation of the legal

[41] www.alp-lab.at
[42] www.testregion-digitrans.at/en/
[43] www.digibus.at/en/
[44] www.bmvit.gv.at/en/verkehr/automated/index.html

framework, the development of domestic competences through research and development and a stronger role for the public sector in shaping the future use of automated mobility. Additionally, the adaption of driver education has to be dealt with in respect to assisted and automated driving.

Belgium

The Flemish government in March 2018 adopted a policy note on connected and automated mobility to realise investment priorities for a smart and safe transport system in Flanders, including regulatory aspects. Research for autonomous vehicles (functional safety, path planning, control and ADAS information functions) is carried out by Strategic Research Centres, amongst others the program Autonomous Vehicle and Infrastructure Cooperative Architecture (AVICA), enabling Flemish OEMs, Tier-1 suppliers and infrastructure, component and service providers to provide proof of concept of their products at system level.

Field Operational Tests on connected and autonomous driving are implemented by knowledge partner imec in the framework of the CONCORDA project, complemented with the Flanders' publicly funded innovation project SmartHighway, and a recent public private innovation partnership, Mobilidata, on cloud service applications for smart traffic infrastructure.

The Walloon government decided to upgrade its mobility management center called Perex and to turn it into a Perex 4.0 mobility management center. This represents an investment of around 30 millions of EUR and will allow this center to manage highways, roads and waterways in the same system. In the framework of the Walloon Competitive Clusters policy, the Walloon government has decided to finance a collaborative RD&I project called "Viaduct". This project aims at designing, developing and validating of novel products and services based on human machine multimodal interface, centered on voice, for the semi-autonomous driving and focusing on senior people.

The Brussels Region is working on an action plan for its mobility strategy called Good Move (2018-2040), in which there will be a section dedicated to the deployment of new mobility services, which include autonomous vehicles. The Brussels Region mobility service provider STIB will test its first autonomous vehicles in Summer 2019.

Under the umbrella of JPI URBAN EUROPE, Innoviris, the Brussels Institute for Research and Innovation is taking part in the ERA-NET COFUND for connectivity and accessibility in which some of the topics are of strategic relevance for the region. Innoviris is currently funding a pilot project for an automated shuttle service at and around the Health Campus of the Universitair Ziekenhuis Brussel (UZB). This project aims to evaluate how an automated shuttle service can facilitate mobility for all stakeholders in the private and public domain. It is also trying to identify best practices for the implementation of a pilot project for autonomous vehicles in Brussels.

Czech Republic

The strategic framework for connected and automated transport is set by the "Vision of autonomous mobility development", a strategic document approved by Czech government in October 2017. Research and development activities and testing constitute one of its focus areas. As a follow-up, an Action Plan for Autonomous Driving is expected to be approved in February 2019, aiming at developing concrete actions including research and innovation programs focused also on CAT.

C-Roads Czech Republic (funded by Connecting Europe Facility) is being implemented until December 2020 with a primary objective to harmonise the provision of services for mutual data communication between vehicles and communication between vehicles and intelligent transport infrastructure. This project is part of the European C-Roads platform, whose the objective is to create a harmonised functional system among individual European projects for cross-border use of services involving cooperative intelligent transport systems (C-ITS), thus preparing an environment for the operation of cooperative and, in the near future, autonomous vehicles. Road traffic data exchange between vehicles and road infrastructure involves also public transport. The cities of Ostrava and Pilsen are among the first "smart" European cities where C-ITS roadside units have been installed, e.g. on parts of the Ostrava tram lines and at the intersections in Pilsen. The project also addresses the use of C-ITS at railway level crossings.

Finland

The Arctic Challenge (2017-2019) research project is looking into finding solutions to automated driving challenges in adverse weather conditions. It examines e.g. the use of different supplemental positioning methods to accurately localize the vehicle on the road when no road markings are clearly visible. The FABULOS project seeks new solutions and technologies to prepare cities for the future of mobility, including concepts such as self-driving buses. Novel transport solutions will be developed and acquired by utilizing Pre-Commercial Procurement, which allows the procuring partners to share the risks and benefits with the suppliers. The expected outcome of the project is the demonstration of automated minibus service.[45]

During 2018-2022 Business Finland's Smart Mobility program focuses on seamless transport chains, emission reduction and big data. The Smart Mobility program supports Finnish companies in taking advantage of the new business opportunities coming from radical changes in the transport sector. In addition, the program aims to attract significant international players into Finland to benefit from test platforms and to build and join new innovation ecosystems. Smart Mobility program is for companies, research organizations, municipalities and cities, e.g. in service, ICT and manufacturing industries.[46]

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[45] fabulos.eu
[46] www.businessfinland.fi/en/for-finnish-customers/services/build-your-network/digitalization/smart-mobility/

France

The French national strategy for the development of autonomous vehicle was published in May 2018. The primary objective of the strategy is to facilitate the emergence, then the deployment, of innovative automation technology, supporting technological progress via a secure framework for industry and public services, and taking into account the development of both the international framework and local expectations and needs. Research priorities include validation of autonomous systems, impacts of autonomous vehicles regarding safety, traffic, environment, etc., human factors and acceptability.

A national experimentation program will cover all types of cases use (personal vehicles, public transport, freight and logistics), involving industrial sectors and local government. The main purpose of this experimentation program is to enable the development of validation tools for automated systems and evaluate acceptability of autonomous vehicles. The “Future Investment Program”, the main French innovation and research program, is mobilized to financially support this experimentation program and a call for project proposals was launched in June 2018.

Moreover collective tools for innovation and research are in place such as ITE Vedecom and IRT SystemX receiving funding from the “Future Investment Program” to conduct research programs on key technologies of the autonomous vehicle. Industry is encouraged to participate in these projects on a model of public-private co-investment for pre-competitive R&D projects. For example, MOOVE is a project conducted by Vedecom, which aims at the acquisition of big data about real world driving in order to provide a full representation of the ego vehicle environment in order to identify safety critical scenarios. The SVA project conducted by SystemX aims at providing a methodology, a platform and simulation tools to design safe autonomous vehicles and validate them.

Germany

Research and innovation funding in the field of automated driving in Germany makes an important contribution to the implementation of the German federal government’s "Strategy automated and connected driving: Remain a lead provider, become a lead market, introduce regular operations" which was published in September 2015. The strategy addresses the following five fields of action: infrastructure, legal aspects, innovation, networking, IT security and data protection. It aims to promote the implementation of automated and connected driving and to "put it on the road".

Major sources of innovation project funding in connected and automated driving in Germany are: The federal government’s Framework Program for research and innovation „Microelectronics from Germany - Driver of innovation for the digital economy‟ (with research funding being implemented by the Federal Ministry of Education and Research), the Research Program on innovative vehicle and systems technologies by the Federal Ministry for Economic Affairs and Energy, and the Research Program on automation and interconnectivity in road transport by the Federal Ministry of Transportation and Digital Infrastructure.

An example for a relevant current German project preparing the implementation of connected and automated driving is PEGASUS, covering the testing and release of highly automated driving functions.[47] Data formats and requirements for training and testing AI-based systems for automated driving are currently being studied within the project KI-Plattform. The project GENESIS aims at a new platform for assessment and certification of AI for autonomous driving, operated by DFKI and TÜV Süd. Within the academia-driven project UNICARagil, novel, modular vehicle concepts and electric/electronic architectures for driverless electric cars are being developed. Finally, there is the project KOHAF which realized highly automated driving on highways supported by backend information (layer based digital map).[48]

Hungary

The governmental decision for building a unique automotive proving ground dedicated for connected and automated vehicle testing and validation (ZalaZONE[49]) took place in 2016. Phase one of the constructions is ready, meaning that certain sections of the proving ground are already available for the customers. According to the plans, the fully functional proving ground will be ready by end of 2020. The related activities are coordinated by the Ministry of Innovation and Technology. Moreover, Hungary has modified the traffic regulation to support CAV testing on public roads. Since April 2017 it is allowed to test automated vehicle functions on Hungarian public roads without territorial or time limitations. Together with Austria and Slovenia there is a tri-lateral cooperation signed for the establishment of a three-country cross-border CAV testing environment.

Latvia

"Guidelines on Testing Automated Vehicle Technologies" were elaborated by Latvian stakeholders and adopted by the Ministry of Transport in the beginning of 2018. The Guidelines set out requirements for testing automated vehicles on publicly accessible roads in Latvia, thus reducing the potential risks associated with the participation of such vehicles in traffic.

As part of the Interreg BSR programme, Zemgale Planning Region is participating in the Sohjoa project, which includes a study entitled "Research of Legal Regulatory Changes for Testing and Implementing Automated Vehicles and Their Technology". Work is currently under way to identify the exact routes in Aizkraukle and Jelgava cities, where a pilot project launching an automated bus could be carried out.

Netherlands

On the National level, a Smart Mobility policy letter recently (on 4 Oct 2018) was sent to the Dutch Parliament which included four action lines: stimulating the use of existing products and services, responsible introduction of new

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[47] www.pegasusprojekt.de
[48] www.ko-haf.de
[49] www.zalazone.hu

generation vehicles, future proof infrastructure and road maintenance and meticulous utilization of data exchange and connectivity. Also recently, new legislation has made it easier to undertake and learn from road experiments in FOTs. In the Netherlands, the most large scale FOT's are coordinated via the "TULIP-NETWORK", where CAD projects like The Amsterdam Experiment, SOCRATES, CONCORDA, C-ITS, TALKING TRAFFIC and many more are connected. Also in the Eindhoven/Helmond area and province of Brabant there are many FOTs and an extensive (Smart) Mobility program called SMARTWAYZ. The TULIP-NETWORK is intended to connect the Dutch FOTs and help them to learn from each other. On the policy level there are discussions about how to "connect the dots" between the fragmented Smart Mobility developments in the Netherlands and within Europe. There are for instance over 50 small scale experiments in the Netherlands concerning automation in public transport. Other initiatives include: The Netherlands Truck Platooning FOTs, a TNO Whitepaper on Truck Platooning, and a Superroute app: Dutch initiative, i.e. a collaborative effort between the Municipality of Amsterdam, the metropolitan region, the Province of Noord-Holland, Rijkswaterstaat, TNO, ARS Traffic & Transport Technology, and PrimeData company.

Poland

The INNOSBZ sectorial program is aimed at increasing the competitiveness and innovativeness of the Polish sector of unmanned systems production on the global market in the perspective of 2023/2026. The thematic areas on which the activities of the Program are focused are: Unmanned aerial vehicles, unmanned land platforms, and unmanned waterborne platforms (Group I), and subsystems, subassemblies and technologies for unmanned platforms, as well as industrial applications for the mission of crisis management support, protection of critical infrastructure, environmental protection and industrial supervision (Group II).

Portugal

Portugal has been actively preparing the necessary context to safely accommodate the technological evolution for vehicles progressively equipped with higher levels of automation. In April 2016, Portugal was one of the 'Amsterdam Declaration' signatories, where a commitment was made to work together to ensure the successful implementation of intelligent technologies and to contribute to a connected and autonomous vehicles shared vision. With this perspective, the national participation in two European reference projects is fundamental: C-Roads Portugal and AutoCITS.

C-Roads Portugal - which is part of the European C-Roads platform - is promoted by the national ministry - Ministério do Planeamento e das Infraestruturas (MPI) and coordinated by Mobility and Transport Institute - Instituto da Mobilidade e dos Transportes, IP (IMT, IP). It intends to implement and evaluate Day-1 C-ITS services performance, such as most problematic road network places notification, congestion warnings or vehicle speed optimization based on the green time (so-called GLOSA), as well as to test some of the most advanced Day-1.5 services.

The Autocits Project, which integrates the National Highway Safety Authority (Autoridade Nacional de Segurança Rodoviária - ANSR), intends to contribute to C-ITS services implementation by increasing interoperability of autonomous vehicles and at the same time, encourage the role of C-ITS services as a promoter for autonomous driving development, making Portuguese roads safer and generating other positive externalities such as the promotion of more efficient mobility and the reduction of road transport emissions.

Spain

Spain already has developed some national strategies where autonomous driving is identified as a key area:

(1) The Spanish Agenda for the Automotive Industry (2018) contains 20 priorities for 2020. It will be the framework for the development of the R&D priorities (developed by Move2Future, Spanish Mobility Technology Platform) for the automotive sector (2018) in which "safe mobility more autonomous" was identified as a key topic.

(2) The DGT 3.0. Connected Vehicle Platform (2016) by the Directorate General of Traffic promotes the use of a technological platform that allows being connected and offers traffic information in real time to road users. It will enable a safer and smarter mobility. The challenge is to achieve zero deceased, zero injured, zero congestion and zero emissions.

(3) The Spanish R&D Strategy for the period 2013-2020 (2013) is totally aligned with the Horizon 2020 priorities where automated road transport is fostered. As part of the Spanish R&D calls, the "Cervera Network" has recently been published by the Ministry of Science, Innovation and Universities with 600 Million EUR of Budget for different sectors. It has the following objectives in the area of CAD: (a) Development of digital instrumentation applicable to assisted driving for the increase of safety through anti-collision sensory systems, using intelligent action systems that increase active and passive safety. This also includes the development of communication systems for the connectivity of vehicles to the infrastructure prepared for autonomous driving; (b) Development of intelligent networks (VANET) that include vehicles as network nodes and that respond to the challenge of increasing autonomous and self-guided vehicles, as well as communication and interaction with the rest of the infrastructures in the field of smart cities.

(4) The Spanish Ministry of Public Works and Transport has launched a Transport & Infrastructure Innovation Plan (2017) that develops the innovation strategy covering CADs.

In additional to reflecting the relevance of CAD in the latest policies at national level, Spain has been working on the releated technologies for many years. Back in 2001, the two first autonomous vehicles were presented by the Technical University of Madrid (INSIA) and the Spanish Council for Scientific Research (CAR), followed by the development of the first cooperative autonomous driving system based on V2V communications, in 2003. In 2012, the first 100 km autonomous route on public roads in Spain, with a highway track between El Escorial and Madrid was organized by INSIA and CAR, as well. A total of seven fully autonomous vehicles equipped with several V2X communications systems, sensors and cooperative systems were tested.

The automated vehicles regulation by Directorate-General of Traffic (DGT) issued a regulation to permit fully automated driving tests (2015). This regulation permits field operational tests in all the territory in different test sites that are already equipped to host field operational tests (controlled Test Sites, Urban and InterUrban).

Sweden

DriveSweden[50] is a government-sponsored collaboration platform running from 2016 until 2027 with over 100 partners, aiming to design and pilot new mobility services based on connected, automated and shared vehicles. The Swedish Transport Agency, can since 2017 authorize test trials with autonomous vehicles in real life mixed traffic environments if certain conditions are met.

The FFI[51] partnership program is the main program for automotive research in Sweden funded by the innovation agency Vinnova, the Swedish Energy Agency, the Transport Administration and the main automotive stakeholders in Sweden. The FFI program covers several important areas for connected automated driving, such as "Road Safety and Automated Vehicles", "Electronics, Software and Communication", "Efficient and Connected Transport System", "Systems-of-systems", "Cyber-security for automotive" and Electro-mobility.

Sweden also participates in several CEF-funded projects, such as NordicWay and EU EIP, where early deployment issues regarding connected and autonomous vehicles and related requirements for a digital road infrastructure are addressed on a European level.

United Kingdom

As outlined in the Mayor's Transport Strategy, Transport for London (TfL) is involved in a number of government funded trials of autonomous vehicle technology to ensure learnings as the industry develops as well as ensure that it is carried out in a safe and environmentally-friendly way which complements the focus on walking, cycling and green public transport.

[50] www.drivesweden.net/en
[51] www.vinnova.se/en/m/strategic-vehicle-research-and-innovation/sub-programmes-and-strategic-initiatives/

# 6 Research and Innovation Initiatives

*In this chapter, the structure of the roadmap, consisting of thematic areas, R&I initiatives and actions is introduced, the content of the thematic field is described and the list of R&I initiatives is presented. Furthermore the assessments of timing, priority, responsibility and interlinks resulting from consultations with multiple stakeholders from the European Commission, Member States governments, industry and academia are summarized, compared and commented on at the level of the R&I initiatives.*

## *6.1 Structure of the Roadmap*

The roadmap is indicating what needs to be done in order to close the gaps and seize the opportunities of CAD in Europe as described in chapter 3. It is structured into three key elements, namely thematic areas, R&I initiatives and actions.

Thematic areas are the division of themes for research and innovation in the field of connected and automated driving. In total 8 thematic areas have been proposed.

R&I initiatives are concrete activities and undertakings to be implemented by stakeholders in order to achieve the European Union's goals in the area of connected and automated driving. They are described in terms of objectives, state of the art challenges as well as impacts. There are several initiatives per thematic area.

Actions describe in sequence the content, timing, instruments and responsibilities of all activities that according to the involved stakeholders have to be implemented within each of the R&I initiatives. In the process of consultations on the roadmap, the actions were summarized in action sheets (one per R&I initiative).

The thematic areas, the lists of initiatives and actions as well as the related assessments result from an intensive stakeholder dialogue process involving Member States representatives and experts from industry and academia in discussion on challenges and priorities at two workshops, held in Brussels on May 17, 2018, and September 13, 2018. Even though the initiatives and actions are assigned to technical areas of research and development, they include horizontal activities such as system architecture development, harmonization and standardization as well.

## 6.2 Thematic Areas and List of R&I Initiatives

*In the following, the eight thematic areas of CAD covered by this roadmap are briefly described and the list of initiatives is indicated for each thematic area. This will be followed by assessments of the initiatives in terms of priority, timing, responsibility, and links. A more detailed description of the actions within each initiative is contained in chapter 7.*

1. <u>In-vehicle enablers</u>

   To deliver on the promises of increasing traffic safety by reducing the number of incidents and the impacts of accidents in all Operational Designs Domains (ODD), to ensure safe operation under extreme weather conditions and also to improve driver and passenger comfort while ensuring the trust of all road users, in-vehicle technologies will be further advanced so that the most robust and best achievable environment perception can be achieved. Safety expectations by the society will be translated into standards for the performance of sensor suites for different automation levels and ODDs. Moreover, it will be ensured that in-vehicle systems are fail-operational and cyber secure preferably in all ODDs. This implies to define minimum-risk requirements and to develop and test next generation operationally safe and cyber secure in-vehicle systems. The follow-up implementation will be in line with the EU "Cyber Security Act". More generally, European ODDs will be defined to enable the development and testing CAD vehicle decision processes according to different regional requirements in Europe in different traffic and road situations. The implementation of these ODDs will be supported in Europe and beyond, also towards international standardization.

   *R&I initiatives:*

   1.1. Reliable environment perception to identify and predict all hazards in CAD
   1.2. Fail-operational and cyber secure electronic and software control archi-tectures for CAD
   1.3. ODD for Safe, Unambiguous On-board decision making

2. <u>Vehicle Validation</u>

   The complexity of CAD-related technologies and functionalities poses the risk of creating a big gap between developers and validators/certifiers. Therefore, a common testing framework will be established to ensure that testing and validation of CAD vehicles and their subsystems is carried out in all Member States and by any OEM or supplier in the automotive chain according to a common set of qualified methodologies and procedures. The framework includes the testing of driving skills of highly automated vehicles (addressing concepts like a software driver's license for automated vehicles) and the integrated testing of interactions between vehicle, infrastructure and human driver. This framework will be as technology agnostic as possible though as specific as needed and inclusive for a holistic assessment of automated vehicle safety and behaviour under different conditions (day and night, weather, traffic parameters, road types and geometrical characteristics, etc., across borders), taking into account also human factors and interactions with the aim of meaningful human control. The process will be designed to be flexible enough to integrate future technologies, e.g. over-the-air (OTA) updates, artificial intelligence (AI) technologies, etc., as well as connected and cooperative systems, for different Operational Design Domains (ODD). New accident types will be considered in the assessment methodology, and automation will be assessed in continuous and possibly long driving sessions, with reference to scenes and circumstances defined ad-hoc.

*R&I initiative:*

2.1. Common testing and validation methodologies ensuring the correct functionality, performance and safety of AV and the comparability of the different activities

3. <u>Large scale demonstration pilots to enable deployment</u>

Large-scale pilots and field operational trials (FOT) will ensure safety, provide valuable insights in the abilities of automated driving systems (ADS) and their current limitations. Large-scale pilots with prototype vehicles provide data for verifying and validating ADS ensuring safety and reliability before market introduction. Demonstrations with small series production passenger vehicles (i.e. FOTs) will raise user awareness, help assess the impact on society and accelerate implementation. For these FOTs, Living Labs[52] provide the necessary infrastructure (including connectivity) and user communities. The coordination of Living Labs for ADS is important to foster harmonization and interoperability and support cross-border functionality all over Europe. For automated freight transport applications, large-scale demonstration, pilots and pre-deployment (e.g. FOTs) activities will deliver evidence for quantifiable transport objectives such as increased freight transport efficiency, improved road infrastructure utilization, reduced energy consumption, increased safety, enhanced traffic flow and improved working environments. For bus and shuttle applications, in addition, improvements of operation efficiency in urban and sub-urban environment and human-machine interaction will be measured. Large scale demonstrations will also be used to integrate automation with clean propulsion technologies (electrification of road transport) and connectivity (to ensure global mobility, improve operations and improve maintenance). Finally, a European platform will be set up to group all relevant public and private stakeholders for a coordination of open road testing by developing a common European testing agenda, defining common use cases for testing and methods for impact assessment, supporting exchange of knowledge and investigating required infrastructures.

[52] Living Labs refer to user-centered open innovation ecosystems. The enable the co-creation, exploration, experimentation and evaluation of innovative ideas, scenarios, concepts and related technological artefacts in real life use cases.

*R&I initiatives:*

3.1. Deployment of connected automated passenger vehicles in real (mixed) traffic conditions for improved safety and efficient road transport
3.2. Deployment of connected automated heavy commercial freight vehicles (CAD-HCV) in mixed traffic for improved safety and efficient road transport
3.3. Deployment of electric, connected and automated buses and shuttles in mixed traffic for improved safety and efficient road transport
3.4. European stakeholder platform to coordinate open road testing

4. <u>Shared, connected and automated mobility services for people and goods, including long haul transports (persons, goods, public)</u>

In view of the potential of shared, connected and automated mobility services for achieving the EU’s objectives for urban, peri-urban and interurban mobility, the attractiveness and business viability of such new mobility services for people and goods will be demonstrated. In particular, economically and environmentally viable, highly personalised, safe and secure transport services will be studied, where the automated vehicle services (like itinerary, time table etc.) are dynamically adapted to the individual user needs for both urban and peri-urban mobility. This will require access rights to the necessary data for service providers and consumers on fair, reasonable and non-discriminatory terms. More research will be implemented to show how traffic and fleet management can build on the new automated mobility services and how fleet and traffic management can help to manage issues like mixed traffic, and enable new services.

*R&I initiatives:*

4.1. Design and plan attractive and acceptable shared and automated mobility services for passengers and goods (and combinations thereof)
4.2. Integration and implementation of shared automated vehicles services with existing urban/regional mobility
4.3. Bi-directional enabling of fleet and traffic management and new mobility services

5. <u>Socio-economic impacts; User/public acceptance</u>

Reflecting the opportunities and problem solving capabilities of CAD, user requirements will be considered in their broadest sense and with elements influencing trust and acceptability of novel technologies, particularly also involving people in need of special attention (special needs, disabled, elderly people). More generally, potential impacts on driver attitudes and behaviour, influencing traffic safety, will be analysed, and ethical and liability aspects related to CAD will be studied. This shall lead to policy recommendations for making best use of automation in transport and in relation to an expected transition period comprising mixed fleets. The research will cover spatial planning impacts of CAD, study its affordability, and assess the incentives and regulations needed to ensure environmental friendly use of AVs in an eco-system of shared mobility using electric vehicles of all sizes. The initiatives of this thematic field also focus on the assessment of the social and ethical impacts of connected and automated vehicles, the impact of large-scale tests of CAD systems and the need for a commonly agreed methodology to assess long-term impacts. Finally, it will be assessed how the value chains and the work force in the European Union can adapt to new and fast changing framework conditions and technological evolutions of CAD.

*R&I initiatives:*

5.1. Analysis of societal needs, citizen expectations, and public acceptance (in urban areas, but also beyond) in relation to CAD
5.2. Social and environmental impact assessment of connected and automated vehicles
5.3. Foster workforce and skills development in digital technologies for CAD

6. <u>Human factors</u>

The objective of this thematic field is to create new designs for high user acceptance, trust and reliance on automated systems by well-designed, user relevant and informative Human-Machine Interfaces (HMI) allowing intuitive and seamless transfer of control between the driver and the vehicle, and also responding to the needs of users with special requirements (e.g. visually impaired, disabled, etc.). In particular, the functional interaction between automated vehicles and users will be designed in a safe and intuitive way and task division and interaction between the automated vehicle and driver, including the minimum time required to resume manual control will be solved. Moreover, the interaction between automated vehicles and road users will be facilitated in a safe, efficient and cooperative way. Also, related needs for driver education and driver training will be defined, and harmonization and standardization of HMI frameworks for automated vehicles and communication patterns of CAV for interaction with other human traffic participants will be supported. Finally, methods and systems will be developed for driving a cooperative automated vehicle from a remote control station achieving tele-operation of the vehicle. Use cases for taking over the control from the automated vehicle by the tele-operator and / or use cases for only tele-operated vehicles in early automation scenarios and pilot studies will be explored and tele-operation workplaces for viable HMI designed.

*R&I initiatives:*

6.1. Develop and establish smooth communication and interaction between automated vehicles and their users
6.2. Ensure unambiguous communication between vehicles and other (vulnerable) road users
6.3. Determination of opportunities and limits of tele-operation for automated vehicles

7. Physical and digital infrastructure and secure connectivity

It will also be explored how Physical and Digital Infrastructures (PDI) and secure connectivity integrate public and private transport, especially with regard to data exchange and access as well as related business models. New design concepts will be jointly agreed upon by vehicle manufacturers, fleet operators and road operators. These shall improve traffic management by better advisory functions and stronger control of vehicles in order to increase capacity in the existing road network. A focus will be on special areas like crossings, road-work zones, tunnels, urban environments, special events, natural disasters and handover situations. It is also foreseen to study how CAD use cases depend on connectivity to reach performance goals regarding safety, security, efficiency and service requirements. This implies to assess the performance in hybrid communication environments from an end-to-end perspective, to continue data-driven assessment in real-world driving conditions, and to identify links between safety vs. security and privacy. Particularly, holistic solutions for cyber security of the AV ecosystem will be developed. Therefore, methodologies and requirements for end-to-end security of transmitting sensor data and control data will be developed, needs in terms of accuracy, interoperability and responsibilities of data will be assessed, and cyber security by design will be explored. Additionally, infrastructure support will be categorized based on the Infrastructure Support for Automated Driving levels. Therefore, a common understanding will be needed on the overall system architecture and its assessment frameworks, as well as on standardization and harmonization needs and international benchmarks.

*R&I initiatives:*

7.1. Physical and digital infrastructure (PDI) for enabling increasing levels of automation
7.2. Reliable and effective traffic, network and incident information management
7.3. Adequate connectivity (reliability, quality, coverage, security) for higher levels of automation, also across borders
7.4. Cyber Security of CAD-related operations including data exchange & sharing

8. Big data, Artificial Intelligence and their applications

The sensors of connected and automated vehicles produce huge amounts of data. In addition, similar if not larger amounts of information are gathered from road infrastructure sensors, mobile phones, from meteorological instruments and other systems related to transport. To accelerate the development and assessment of CAD technologies and to support the optimization of road usage, the availability, quality assurance, interoperability, and the exploitation of this big traffic data is ensured. Moreover, models for data sharing and making data accessible are needed. Also, new and innovative business services based on big data that respect the security, privacy and the highest ethical standards are generated. Therefore, 'new' AI concepts and technologies will be developed to fulfill the challenges and responsibilities of CAD functions taking into account innovative infrastructures and new vehicle function. Operational safety will also be ensured. To achieve this, further collaboration on the ways to develop, train and validate the AI and on the availability of testing sites (both in closed environments and in open test-beds) will be fostered.

*R&I initiatives:*

8.1. New tools and models for storage, usage and sharing of valuable data

8.2. Further development and use of Artificial Intelligence in road vehicles (on and off-board) and in the digital infrastructure

### *6.3 Assessments of the Initiatives: Priority, Timing, Responsibility, Links*

Prior to an in-depth consideration of the actions defined for each R&I initiative in the next chapter, here, a comparative assessment of the initiatives themselves is made. This analysis is based on voting and discussions among the stakeholders from the European Commission, Member States, industry and academia involved in the process of drafting the roadmap at hand at the second stakeholder workshop.

Inevitably, the analysis is biased by the composition of the group, which included more public authorities than industrial stakeholders. Thus, investments in public services and infrastructures are generally preferred to developments in business domains.. Also, due to different thematic focusing and width of content, the initiatives are not always easy to compare. Therefore, the assessments have been reviewed critically by the stakeholders at the workshops, and notes have been taken where the results appeared imbalanced. This shall help to provide a more complete picture.

Assessments have been made on:

- Priority rankings of initiatives (see table 1)
- Timing and types of actions per initiative (see table 2)
- Responsibilities per initiative (see table 3)
- Links between initiatives (see table 4)

The results are summarized below.

Priority rankings of initiatives:

Regarding the Priority Rankings of Initiatives, the stakeholders confirmed that despite of the result of a first voting, all initiatives would be highly relevant for enabling connected and automated driving, and there was no distinction between “need to have” and “nice to have”.

It was suggested, though, that a high score for an initiative indicated that the topic had not yet been fully covered in the previous programs. It also stands out that topics that require research in preparation of decision making on regulation, infrastructure investment and traffic planning are ranked higher than research in support of technical innovations, also pilots and demonstrations are considered to be more relevant than technology development. In the discussions, it was noted, however, that further breakthroughs in key technologies both at vehicle control, human interaction and decision-making levels are essential to enable connected and automated driving at higher levels. In general, it was proposed to seek alignment, e.g. with the EU-wide High-Level Meetings on Connected and Automated Mobility established with the Declaration of Amsterdam in April 2016.

Timing and types of action per initiative

Regarding the timing and types of action per initiatives, for which information was directly derived from the action sheets, it can be stated that for most initiatives, the stakeholders involved see a need primarily for research and innovation actions or multiple actions on a short to medium time scale, i.e. until 2023 or 2030, respectively.

Those initiatives that relate to the embedding and connection of connected and automated road vehicles into systems of mobility and traffic management are seen as likewise urgent, however may potentially require the build-up of infrastructures, which may take beyond 2030 to reach full coverage. Initiatives that are addressing particularly complex issues such as on-board decision-making and commercial vehicle pilots at higher automation levels will extend into the medium to long-term, too. It stands out that many initiatives are rather consisting of a mixture of types for a period of time, e.g. standardization in parallel to research and innovation. Obviously, the need for research and innovation is mostly seen at the short to medium time scale, while the need for actions supporting implementation of connected and automated driving is following thereafter, which is reflecting the regular sequence of innovation readiness levels. Coordination and support measures are merely needed at the early stages of the innovation chain, e.g. where consensus has to be built about expectations, capabilities and responsibilities of various stakeholders; in the case of connected and automated driving this applies to traffic management and testing activities which require the cooperation of multiple stakeholders. Sometimes, however, coordination also serves the purpose of knowledge sharing after research results have been achieved, e.g. in the case of cyber secure electronics where a major challenge consists in promoting standards for the existing technology to remain tamper-proof for the whole lifetime of a vehicle. The stakeholders also pointed out some coordinating actions to be of particular significance, e.g. a European stakeholder platform to coordinate open road testing, a European Forum on Transport and Mobility carrying out an analysis of societal needs, citizen expectations, and public acceptance related to connected and automated driving, and a European Connected and Automated Driving Stakeholder Forum discussing the needs and responsibilities for physical and digital infrastructures among public and private stakeholders.

Responsibilities per initiative

Regarding the responsibilities per initiative, the stakeholders considered the main responsibilities for implementation to lie either with the private ("industry") or the public sectors ("MS", "EC", "Cities") or both: While the development and testing of CAD technologies are seen as a private sector tasks, vehicle validation, the integration into traffic management and the creation of physical and digital infrastructure as well as the analysis of socio-economic impacts, mobility system effects and cyber security are merely considered responsibilities of the public. For the funding of almost all initiatives, public sources are considered to be of relevance.

In the first place, the development of in-vehicle technologies, user interaction, connectivity and artificial intelligence seem to be exceptions as paying the related costs from company budgets might be justified by private sector market interests. However, some stakeholders argued why public funding would be needed for those, too: For instance, academic research in enabling technologies would reduce the risk to breaking new ground and enable creating general insights e.g. on environment perception, integrated controls and artificial intelligence of connected and automated driving that could hardly be justified from a private sector perspective. Besides clear responsibility of the industry in that domain, public funding would also ensure that research on the interaction between automated vehicles and passengers or vulnerable road users is properly reflecting the interests of the society. The stakeholders also stated a need for new partnerships where responsibilities for implementation and funding diverge.

Links between the initiatives

Regarding the links, in some cases inputs to be given to and required by an initiatives match, i.e. awareness exists “on both sides”, probably indicating that the link (or dependency) is quite strong, such that it may be important to plan the actions in the right consecutive order for an accelerated innovation.

Essential information on the links could be drawn from the action sheets since the stakeholders had been asked to indicate which other initiatives a certain initiative depends on, or gives inputs to. Examples for matches include:

- On-board decision-making in the ODD (1.3) has to build on a proper understanding of human vehicle interactions (6.1).
- Vehicle validation (2.1) can be closed only if cyber security concepts (1.2) are available.
- Large-scale demonstrations (3.1-3.3) of CAD require vehicle validation (2.1), first, and build on the existence of an appropriate physical and digital infrastructure (7.1).
- In addition, advanced systems like automated shuttles (3.3) need to be embedded into a traffic management system (7.2).
- Shared automated mobility solutions (4.1) can be developed only if an analysis of societal needs and acceptance (5.1) has been done before, and physical and digital infrastructure is in place.
- The physical and digital infrastructure (7.1) needed for CAD critically depends on non-board decision making capabilities (1.3) of the vehicle in the ODD.
- Solutions for the data related cyber security issues (7.4) of CAD need cyber-secure electronic controls (1.2) in the vehicle as a precondition.
- Big data storage and sharing (8.1) requires adequate connectivity (7.3) and cyber security of data (7.4).
- The application of artificial intelligence (8.2) builds on big data storage and sharing (8.1).

*Tab. 1: Relative priority ranking of initiatives according to voting, and remarks made during review of results at 2nd stakeholder workshop (score decreasing from top to bottom). Note, all initiatives have been considered highly relevant in the end.*

| Rank | # | Short Title of R&I Initiative | Remarks from Review |
|---|---|---|---|
| 1 | 2.1 | Vehicle Validation | |
| 2 | 7.1 | Phys / Digital Infrastructure | |
| 3 | 7.2 | Traffic Management System | |
| 4 | 5.1 | Societal Needs Analysis | User acceptance is essential for CAD |
| 5 | 3.1 | Passenger Vehicle Pilots | |
| 6 | 5.2 | Social & Env Impact Analysis | |
| 7 | 3.3 | Automated e-Shuttle Pilots | |
| 8 | 3.4 | EU Road Testing Platform | |
| 9 | 4.1 | Shared Automated Mobility | |
| 10 | 1.3 | On-Board Decision Making | |
| 11 | 4.2 | Mobility System Integration | |
| 12 | 3.2 | Commercial Vehicle Pilots | |
| 13 | 7.4 | Cyber Security of Data | |
| 14 | 8.2 | Artificial Intelligence | should be one of top 5 from industry view |
| 15 | 6.3 | Tele-Operation | |
| 16 | 7.3 | Adequate Connectivity | |
| 17 | 1.2 | Cyber-secure Electronics | |
| 18 | 8.1 | Data Storage & Sharing | |
| 19 | 6.2 | Vehicle-Road User Comm. | safety relevant – should be in the top 10 |
| 20 | 1.1 | Environment Perception | more important as sensor suites are essential |
| 21 | 6.1 | Vehicle-User Interaction | human factors are essential for CAD |
| 22 | 4.3 | Fleet & Traffic Management | |
| 23 | 5.3 | Workforce Development | |

*Tab. 2: Timing and types of action per initiative derived from suggestions made by the involved stakeholders in the action sheets.*

| # | Short Title of Initiative | Short Term | Medium Term | Long Term |
|---|---|---|---|---|
| 1.1 | Environment Perception | R&I | R&I | |
| 1.2 | Cyber-secure Electronics | R&I | Coordination | |
| 1.3 | On-Board Decision Making | Coordination | R&I | Coordination |
| 2.1 | Vehicle Validation | Multiple | Multiple | Implementation |
| 3.1 | Passenger Vehicle Pilots | R&I | R&I | |
| 3.2 | Commercial Vehicle Pilots | R&I | R&I | R&I |
| 3.3 | Automated e-Shuttle Pilots | R&I | R&I | |
| 3.4 | EU Road Testing Platform | Coordination* | | |
| 4.1 | Shared Automated Mobility | Multiple | Multiple | Implementation |
| 4.2 | Mobility System Integration | Multiple | Multiple | Implementation |
| 4.3 | Fleet & Traffic Management | Coordination | Multiple | R&I |
| 5.1 | Societal Needs Analysis | R&I | Coordination** | |
| 5.2 | Social & Env Impact Analysis | Multiple | Multiple | |
| 5.3 | Workforce Development | R&I | R&I | |
| 6.1 | Vehicle-User Interaction | R&I | R&I | |
| 6.2 | Vehicle-Road User Comm. | R&I | R&I | |
| 6.3 | Tele-Operation | | R&I | |
| 7.1 | Phys / Digital Infrastructure | R&I *** | Multiple | |
| 7.2 | Traffic Management System | R&I | Multiple | Implementation |
| 7.3 | Adequate Connectivity | R&I | R&I | R&I |
| 7.4 | Cyber Security of Data | R&I | R&I | |
| 8.1 | Data Storage & Sharing | R&I | Multiple | |
| 8.2 | Artificial Intelligence | Multiple | | |

Types of actions:
Coordination(green): focus on coordination and knowledge sharing, e.g. Coordination and Support Actions;
R&I (red): focus on research and/or innovation, e.g. Research and Innovation or Innovation Actions;
Implementation (blue): focus on implementation, e.g. Field Operational Tests, Living Labs;
Multiple (grey): multiple types of actions in parallel.

Special types of actions:
*: Stakeholder Platform
**: European Forum on Transport and Mobility (follow-up of MOBILITY4EU project)
***: European CAD Stakeholder Forum

*Tab. 3: Main responsibilities per initiative, as suggested by the stakeholders involved in the in second workshop*

| # | Short Title of Initiative | Implementation | Funding |
|---|---|---|---|
| 1.1 | Environment Perception | I | I, EC/MS* |
| 1.2 | Cyber-secure Electronics | I | I, EC/MS* |
| 1.3 | On-Board Decision Making | I | I, EC/MS* |
| 2.1 | Vehicle Validation | EC | EC |
| 3.1 | Passenger Vehicle Pilots | I / Cities | EC, MS |
| 3.2 | Commercial Vehicle Pilots | I | EC |
| 3.3 | Automated e-Shuttle Pilots | I / MS / Cities ** | MS |
| 3.4 | EU Road Testing Platform | EC | EC |
| 4.1 | Shared Automated Mobility | I | EC |
| 4.2 | Mobility System Integration | MS | MS |
| 4.3 | Fleet & Traffic Management | MS | MS |
| 5.1 | Societal Needs Analysis | MS | MS, EC |
| 5.2 | Social & Env Impact Analysis | MS | MS, EC |
| 5.3 | Workforce Development | MS | MS, EC |
| 6.1 | Vehicle-User Interaction | I | I, EC/MS*** |
| 6.2 | Vehicle-Road User Comm. | I | I, EC/MS*** |
| 6.3 | Tele-Operation | I | I |
| 7.1 | Phys / Digital Infrastructure | MS | MS, EC |
| 7.2 | Traffic Management System | MS | MS, EC |
| 7.3 | Adequate Connectivity | I | I, EC/MS**** |
| 7.4 | Cyber Security of Data | EC | EC |
| 8.1 | Data Storage & Sharing | I | EC, I |
| 8.2 | Artificial Intelligence | I | I, EC/MS* |

EC: European Commission
MS. Member States
I: Industry (and research institutes)
Cities: City governments
* EC/MS to contribute to funding the research
** MS and city governments to form partnership
*** EC/MS bring in societal responsibility
**** I and EC/MS to form partnership ensuring coverage

*Tab. 4: Links between initiatives indicating appropriate order and acceleration potentials as derived from the action sheets edited by the involved stakeholders*

| (Line) Gives Input to (column)... / g | (Column) Requires input from.. (line) / r | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1 | 1.2 | 1.3 | 2.1 | 3.1 | 3.2 | 3.3 | 3.4 | 4.1 | 4.2 | 4.3 | 5.1 | 5.2 | 5.3 | 6.1 | 6.2 | 6.3 | 7.1 | 7.2 | 7.3 | 7.4 | 8.1 | 8.2 |
| 1.1 | | | | r | r | r | r | | | | | | | | | | r | x | r | r | r | | |
| 1.2 | | | | x | r | r | r | | | | | | | | | | r | r | r | r | x | | |
| 1.3 | | | | r | r | r | r | | | | | | | | | | | x | r | r | r | | |
| 2.1 | | | g | | x | x | x | r | | | r | | | | | | | | | | | | |
| 3.1 | | | | g | | | | | | | | r | | | | | | | | | | | |
| 3.2 | | | | | | | | | | | | r | | | | | | | | | | | |
| 3.3 | | | | | | | | | g | r | | r | g | g | g | g | | | | | | | |
| 3.4 | | | | | x | x | x | | | | | | g | | | | | | | | | | |
| 4.1 | | | | | | | | | | r | | | | | | | | | | | | | |
| 4.2 | | | | | | | | | | | | | r | | | | | | | | | | |
| 4.3 | | | | | | | | | | | | | | | | | | | r | | | | |
| 5.1 | r | | | r | r | | | | x | g | g | | r | | | | | | | | | | |
| 5.2 | | | | | r | | | | | | | | | r | | | | | | | | | |
| 5.3 | | | | | | | | | | | | | | | g | | | | | | | | |
| 6.1 | | | x | g | | | | | | | | | | | | | | | | | | | |
| 6.2 | | | g | g | | | | | | | | g | | | | | | | | | | | |
| 6.3 | | | | | | | | | | | | | g | g | | | | | g | | | | |
| 7.1 | r | | | | x | x | x | | x | | | | | | | | r | | g | | | r | |
| 7.2 | | | | | g | g | x | | | | r | | | | | | | | | | | | |
| 7.3 | | | | | g | g | g | | | | | | | | | | r | r | | | | x | g |
| 7.4 | | | | | g | g | g | | | | | | | | | | r | r | | | | x | g |
| 8.1 | | | g | | g | g | g | | g | g | r | | | | | | | | g | | | | x |
| 8.2 | | | | | g | g | g | | g | g | | | | | | | | | g | | | | |

g: (initiative in line) gives input to (initiative in column)
r: (initiative in column) receives input from (initiative in line)
x: both match due to strong link between initiatives

# 7 Action Plan

*In this chapter, as the core of the roadmap, the comprehensive framework of actions for the various R&I initiatives as described in chapter 6 is outlined. While the complete list of all actions includes assessments on instruments, timings, and responsibilities for implementation and funding made by the involved stakeholders, an overview of the most relevant information for each R&I initiative is summarized here.*

## *7.1 Comprehensive Action Plan*

All actions suggested by the involved stakeholders for the various R&I initiatives of the eight thematic fields are summarized in a table (see annex). The content in terms of action descriptions, instruments, responsibilities for implementation and founding sources has been extracted from dedicated action sheets that have been developed for each of the R&I initiatives by the involved stakeholders and were discussed at the workshops. For better comparability, in the table (see annex), the actions have been reduced to a very brief description of the main ideas, and some re-ordering has been applied.

## *7.2 Description of Actions per R&I Initiative*

In table 5, the content of the actions is summarized for each of the R&I initiatives.

*Tab. 5 Brief description of content of the actions per R&I initiative*

| **1** | **In-Vehicle Enablers** |
|---|---|
| *1.1* | *Environment Perception*<br><br>In parallel to further public R&I funding for the development of vehicle and infrastructure based sensor systems and suites, a standardization mandate is needed in the short term to translate the safety expectations of the society into performance requirements for such perception systems. |
| *1.2* | *Cyber-secure Electronics*<br><br>While minimum-risk requirements for fail-safe operation and cyber security of the electronic systems of an automated vehicle require further research funding, technologies ensuring cyber security over a vehicle’s lifetime need to be harmonized in standards, and on the medium term, a central “watchdog” for cyber security of CAD systems needs to be installed. |
| *1.3* | *On-Board Decision Making*<br><br>The further development of on-board decision-making processes for CAD not only requires reliable localization and dynamic map technologies but also needs a EU-wide definition of the Operational Design Domains (ODD) and a common and jointly agreed upon basis of rules, reflecting e.g. regional and cultural differences in driver behavior and implicit or explicit norms, followed by close cooperation between industry and member states. |
| **2** | **Vehicle Validation** |

| | |
|---|---|
| *2.1* | *Vehicle Validation*<br><br>The core activities needed to create a common framework for EU-wide and cross borders testing of CAD functions will support the harmonization of regulations and exceptions at EU level and Member States and the standardization of testing and validation methods. This has to be supported by new methods including risk analysis for operational safety, harmonized virtual assessment methods, a database of test scenarios and adaptations to learning systems using artificial intelligence and over-the-air updates. |
| **3** | **Large Scale Demonstration Pilots to Enable Deployment** |
| *3.1* | *Passenger Car Pilots*<br><br>Level 4 automated passenger car pilots have to be run by industry to demonstrate the automated driving functionality in a variety of real life conditions and use cases and at the same time, to test and harmonize the functionality and provide inter-operability for operation across the borders of EU Member States. The activities should result in the creation of a living lab with physical and digital infrastructure for safe pilots. |
| *3.2* | *Commercial Heavy Vehicle Pilots*<br><br>While the readiness of the logistics sector for connected and automated driving of heavy-duty commercial vehicles still has to be assessed and fostered, a multitude of demonstration pilots should be carried out and publicly funded on the short term, including hub-to-hub, urban, and mixed traffic, followed by pilots of truck platoons on open roads on the medium term, with level 4 automation in a ODD large enough for stable and efficient operations being a long term goal. |
| *3.3* | *Automated e-Shuttle Pilots*<br><br>Demonstration and piloting of automated and electric shuttles has to start from an assessment of the urban public and private transport operators' readiness. In the mid term, it will also require public funding for level 4 automated buses and shuttles as well as platoons thereof in (sub) urban areas, integration of bus rapid transit (BRT) and last-mile shuttles as well as fleet management. |
| *3.4* | *EU Road Testing Platform*<br><br>An EU-wide multi-stakeholder platform should be set up, and seed-funded on the short term, to create a European agenda for precompetitive CAD testing, to coordinate tests, to enable knowledge transfer, impact assessment and data exchange and, on the medium term, to monitor and evaluate the efficiency and effectiveness of the testing agenda. |
| **4** | **Shared, connected and automated mobility services for people and goods** |
| *4.1* | *Shared Automated Mobility*<br><br>User needs regarding shared automated mobility and its inclusion into daily activity chains required coordination in the short term. Afterwards, service offers and business models have to be co-created and modeled for both (inclusive) passenger transport and goods delivery in projects and competitions, requiring public funding in the short to medium term. It shall lead to the development and testing of fit-for-purpose shared and automated vehicles. |

| | |
|---|---|
| *4.2* | *Mobility System Integration*<br><br>Complementing the development of business models and vehicles for shared automated mobility, seamless inter-operability has to be enabled across the underlying digital platforms and the vehicles need to be integrated into the mobility system and into mobility patterns of users, which requires publicly funded research. On the medium to long run, new services arising from the integrated system should be piloted and tested, e.g. in living labs. |
| *4.3* | *Fleet & Traffic Management*<br><br>Not least for ensuring safe and convenient operation (particularly for level 4 in reasonable large ODD and especially in mixed traffic), but also for planning efficient services, shared automated vehicles need to be part of a comprehensive fleet and traffic management with measures being explicit and unambiguous. This requires to reach agreements on targets and roles within the mobility system among multiple stakeholders, as well as funded research on a multitude of aspects, e.g. simulation and big data analysis, impacts on operations and users, total system effects, infrastructure needs, and remote controls in emergency cases. |
| **5** | **Socio-economic impacts and user/public acceptance** |
| *5.1* | *Societal Needs Analysis*<br><br>This initiative, which is putting the user in the center, is aimed at public acceptance of CAD. It implies a multi-stakeholder approach and requires as a matter of publicly funded research to determine the safety level expected by passengers and road users and to assess the diverse expectations, attitudes and needs of particular user groups. Also ethical and liability aspects need to be reviewed before policy needs can be derived. In the medium term, impacts of CAD on spatial planning and user attitudes and capabilities need to be explored. |
| *5.2* | *Social and Environmental Impact Analysis*<br><br>For the assessment of the wider socio-economic and environmental impacts of CAD, first, boundary conditions need to be analyzed and the influence on strategic decision-making has to be explored. Potential benefits of CAD on transport and long term effects on trip planning, mobility behavior and energy consumption are in the focus of the research to be funded under this initiative, which also aims to explore synergies (e.g. with electrification) and to avoid rebound effects |
| *5.3* | *Workforce Development*<br><br>The actions of this R&I initiative consist of publicly funded research to assess the current skills of affected workers (e.g. truck drivers), as well as the impacts on the existing labor market and educational system. The definition of policies for labor market incentives as well as the support of workforce transition from manual to automated transport require further efforts and should lead to regulation. |
| **6** | **Human Factors** |
| *6.1* | *Vehicle-User Interaction*<br><br>HMI of connected and automated vehicles shall be designed following an analysis of human factors challenges and the setting of criteria for transition of control to the driver. On the short to medium term, a standardization mandate should be launched to harmonize related testing and validation procedures to facilitate a safe and swift transition of control in expected and |

| | |
|---|---|
| | unexpected situations. Furthermore, the requirements for driver education need to be explored. |
| *6.2* | *Vehicle-Road User Communication*<br><br>As human-machine interaction is not limited to drivers and passengers but also affects other road users, it is important to understand the interaction of humans as vulnerable road users and automated vehicles in a more general sense, also covering differences due to regional and cultural backgrounds as well as gender, age and special needs. On that basis, the HMI of CAV for other road users can be co-designed and harmonized as part of a research project or a standardization mandate. |
| *6.3* | *Tele-Operation*<br><br>To develop tele-operation as a fallback control measure of CAD in emergency situations. First, the tasks and training needs of tele-operators need to be understood. Later, HMI for tele-operation work should be designed and standardized in research projects. |
| **7** | **Physical and digital infrastructure & Secure connectivity** |
| *7.1* | *Physical / Digital Infrastructure*<br><br>To develop a EU strategy for physical and digital infrastructure (PDI) development for CAD, a close cooperation of OEMs, traffic managers, road operators and users is required. Therefore, a European Forum on CAD should be established in the short term. In parallel, the requirements of the PDI ecosystem should be determined in a structural dialogue with industry, road operators and authorities. Among others, ISAD levels have to be defined, and afterwards, real-world performances should be assessed for different use cases in a living lab. Finally, the provision and use of traffic-relevant information should be studied. |
| *7.2* | *Traffic Management System*<br><br>Starting from research to understand the changes from human to software based control of vehicles, the requirements for traffic management systems to integrate CAD have to be defined, and integrated traffic, network and incident management systems need to be simulated and tested. In the medium and long term, traffic management systems for CAD need to be integrated and implemented in real-world testing settings. This can be done in pilots, FOTs and living labs. |
| *7.3* | *Adequate Connectivity*<br><br>The fail-safe operation, appropriate degradation, privacy protection and end-to-end security provision of network coverage to support, facilitate and improve CAD by increased contextual awareness should be the matter of publicly funded research. In parallel, the connectivity performance needed for safe and secure operation, also across borders, has to be standardized on the medium term. |
| *7.4* | *Cyber Security of Data*<br><br>Research on cyber security of data for CAD in the short term should cover security requirements in a hybrid communication environment as well as potentials for breaking security mechanism. In the medium term, cost-effective mechanisms for cyber security could be validated in a pilot, and finally, test beds need to be adapted to cyber security of CAD, and procedures for cyber security testing and certification have to be developed. |

| 8 | **Big data, Artificial Intelligence and their applications** |
| --- | --- |
| *8.1* | *Data Storage & Sharing*<br><br>*A* ‘standard’ model for data sharing based on open and interoperable programming interfaces (APIs) and access control by defined user rights has to be developed. It shall focus on the data value chains, and data storage needs and the related standards supported by appropriate analytical tools and infrastructure. Probe vehicle, traffic and operation data of CAD can be simulated and tested in a pilot on routing of automated vehicles also in mixed traffic. |
| *8.2* | *Artificial Intelligence*<br><br>Besides a further development of deep neural network-based algorithms for CAD, procedures for training and testing complex AI vehicle control need to be developed, and an ethical, moral framework for the responsible use of AI in CAD has to be established in the short term, and transparency of the algorithms is to be ensured. This shall help to further develop the concepts, techniques and models of AI for CAD. |

# 8 Conclusions and Recommendations

*Taking into account the assessments of the R&I initiatives described in chapter 6, the related actions laid in previous chapter 7 are translated into recommendations for the various stakeholders involved, particularly the European Commission, the Member States and the industry here. These recommendations represent the main result of the roadmap development process in the first part of this document as they describe what needs to be done by whom in order to address the gaps and opportunities in CAD identified in chapter 3 based on a comparison of the state of the art (chapter 2) with the objectives (chapter 1).*

## *8.1 General actions of high relevance and urgency*

The multitude of actions for the various initiatives of the eight thematic fields that have been identified by the stakeholders involved in the edition of this roadmap is showing a great awareness of challenges on the way towards connected and automated driving in Europe. To solve the many technical and non-technical issues in due time and without losing momentum, the actions need to be taken in the right order, with coherence and complementarity, such that synergy potentials can be exploited and resources are used efficiently. At the same time, it is important to note that actions can be linked across initiatives and thematic fields in order to accelerate innovation, e.g. by agile innovation methods such as co-creation approaches, partnerships and living labs. Furthermore, opportunities to advance the introduction of connected and automated driving through international cooperation beyond Europe needs to be taken, on the one hand because it can lead to harmonized market requirements, and on the other as many industrial and mobility system stakeholders are having worldwide innovation activities that could lead to added benefits if better coordinated. Reviewing the assessments by the various stakeholders made for this roadmap, guidance can be given on who should do what with which urgency and importance. Also, "nudging" effects can be identified. Therefore, the findings of chapters 6 and 7 of this roadmap are combined to derive recommendations for the European Commission, the Member States and the industry in the following paragraphs. It should be noted that the following lists of recommendations are ordered along the sequence of thematic fields used throughout the document, i.e. this order is arbitrary and does not imply any ranking. All recommendations are summarized and put on a time line in table 6.

## *8.2 For the European Commission*

The European Commission can take responsibility particularly for those actions that address fundamental and risky research for the benefit of society in the whole of Europe if that is not addressed by the private sector, e.g. due to an inherent market failure. This applies particularly to technologies and infrastructure solutions enabling step changes in safety, emissions, system efficiency, and inclusive mobility related to connected and automated vehicles. Moreover, the European Commission can foster the cooperation of stakeholders for the purpose of knowledge sharing, benchmarking, harmonization and strategy development. In the field of CAD this is the case e.g. for legal and societal impacts, infrastructure needs and cyber security.

In general, the European Commission should develop an EU agenda for testing, in order to maximize coherence and complementarities between ongoing Research and Innovation (R&I) and testing activities in Europe, exploit synergies and identify possible fields for cooperation. The European Commission should also establish a partnership to give a clear long-term framework to the strategic planning of research and pre-deployment programs on connected and automated driving on roads at EU and national levels. This partnership should allow not only to coordinate research and innovation activities and large scale testing of automated driving on roads, but also e.g. develop functional specifications for interoperability making sure that investments at local, regional and national level, both of public and private nature, are complementing each other towards a fully integrated European road mobility system, and that budget on research is limited and spent in the right place and to maximize the output through coordination.

And, as a regulator, the European Commission should also mandate standardization and propose new legislation or common methodologies and guidelines, e.g. in terms of vehicle type-approval, communication and ethics.

In this sense, the following specific measures, derived from assessments made by the involved stakeholders through workshops and action sheets as described in the previous chapters of this roadmap, can be proposed for implementation by the European Commission:

**In Vehicle Enablers**

- Fund research (including high risk research) on advanced perception, fail safe and cyber secure electronics, and decision making for higher level CAD, e.g. under hazardous environmental circumstances such as extreme weather, by calls for academically and industry-driven research and innovation projects.

- Establish a “watchdog” mechanism anticipating and preventing cyber security threats of CAD vehicle systems and the common characterization and implementation of EU-specific operational design domains (ODD).

- Explore solutions for perception system safety performance and lifetime proof of cyber secure electronic architectures and systems for CAD, and launch related standardization mandates where needed.

**Vehicle Validation**

- Fund actions to reach a number of harmonization objectives and articulate methods and tools to be made available in a “validation toolbox”, e.g. acceptable vehicle behavior, user protection, type approval, legislation and sharing of test scenarios

- Finance research on virtual assessment tools and methods as well as creation of testing and validation processes for CAD including artificial intelligence (AI)

- Launch standardization mandate for testing and validation of CAD, after public authorities have agreed on orientation for the approaches.

**Large Scale Demonstration Pilots to Enable Deployment**

- Fund field-operational tests, demonstrations and living labs with close to market technologies for highly automated passenger and freight vehicle services, e.g. truck platooning and last mile delivery, aiming to understand user acceptance and requirements in technologies and physical and digital infrastructures. This should include the testing of innovative connectivity technologies for CAD.

- Support the demonstration of level 4 bus and shuttle systems as well as goods traffic, and foster the development of technologies and business models.

- Foster the setup of a EU stakeholder platform to define a European testing agenda, engaging on methods, PDI needs, and use cases arising from local or regional needs, enabling the exchange of information, and harmonizing on lessons learned.[53]

**Shared, connected and automated mobility services for people and goods**

- Run an urban smart mobility and transport challenge that awards seed funding to the city or regional authority with the concept for the fully automated passenger transport or goods delivery system solution that is best tailored to local context and mobility policies. Such concept shall comprise vehicle and hub technologies, shared business models, digital platform for last mile access logistics chain and traffic management and assess acceptance by users and businesses.

**Socio-economic impacts and user/public acceptance**

- Establish an observatory to assess socio-economic and environmental impacts of future mobility and CAD, also in combination with electric mobility, analyzing citizen's needs (e.g. in terms of safety and inclusion) in a participatory way, co-creating solutions with users, technology providers and regulators, and monitoring their implementation, also developing common methodologies for the socio-economic impact analysis (building on the Mobility4EU project and the European Forum on Transport and Mobility resulting from it).

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[53] See Call for Applications for Single Platform for Open Road Testing and Pre-Deployment of Cooperative, Connected, Automated and Autonomous Mobility, European Commission / DG MOVE (2019).

- Setup an expert group to assess ethical and liability issues of CAD and to propose guidelines, standards and framework conditions with the involvement of national authorities.

- Implement studies and organize a wider debate on labor market effects of connected and automated driving with the public and affected workers, and conclude on push and pull measures to facilitate the transition of work force.

**Human Factors**

- Propose harmonization and training requirements in vehicle-user interaction and promote international standardization of human-machine interfaces (HMI), e.g. through ESO and the EU-US-JPN trilateral working group on automated road transport.

- Commission a study and fund research on the challenges of interaction and communication between CAVs and other road users, taking into account EU diversity of expectations, supporting safety validation processes, and making suggestions for standardization, regulation and international harmonization.

**Physical and digital infrastructure and secure connectivity**

- Establish a European CAD Stakeholder Forum to discuss the strategy on physical and digital infrastructure (PDI) roles and needs for CAD with OEMs, traffic managers, road operators, and users and to identify opportunities for harmonization – e.g. in an expert group comparable to the Sustainable Transport Forum or the C-ITS platform.

- Fund research to prepare the PDI ecosystem for cooperative, connected and automated driving, covering e.g. infrastructure needs for different automation levels, definition of ISAD levels, street design elements, maintenance, redundancy as well as infrastructure based sensing, and provision of traffic data. Also, business and financing models shall be included.

- Foster research collaboration between traffic management centers in Europe to explore changes from human to software-based control, and to study, test and simulate integration of connected and automated driving into traffic, networks and incident management systems.

- Prepare regulation on liability and privacy issues of connected and automated driving by ensuring the interoperability of methods and messages that indicate connectivity performance and degradation of functions in case of limited network coverage, as well as changes at borders and launch standardization mandates.

**Big data, artificial intelligence and their applications**

- Fund collaborative research on data storage and sharing for CAD, aiming at a 'standard model' of data sharing (or the interoperability of coexistent models in view of competition) focused on the data value chain, to be tested with probe vehicle and infrastructure sensing data, and to be standardized.

*8.3 For the Member States The European Member States can take the lead particularly for those measures that require a reflection of regional differences. In the case of CAD, that is e.g. traffic system integration or user expectations in terms of safety. Moreover, real-world testing and living labs of CAD can most effectively be implemented at Member States level where legal exception can be reached in consensus with national, regional and city authorities. Finally, the Member States can effectively exert their joint power within international organizations when promoting a common position from different perspectives. For connected and automated driving, this could e.g. apply to the adaption of type approval regulations at UN ECE level. Based on the findings of this roadmap, the following recommendations can be made towards Member States:*

**In Vehicle Enablers**

- Co-fund high-risk research on advanced perception, fail safe and cyber secure electronics, and decision making for higher level CAD by joint calls for industry-driven research and innovation within a European partnership (e.g. ECSEL)

**Vehicle Validation**

- Actively support a number of policy actions in support of CAD, e.g. in terms of harmonized legislation enabling cross-border testing and adaption of type approval regulation at EU level, based on discussions within funded projects, and covering vehicles, infrastructures and humans.

**Large Scale Demonstration Pilots to Enable Deployment**

- Provide the necessary legal framework conditions and exceptions for demonstration and testing of advanced automated passenger car, truck and bus technologies, e.g. in the contexts of living labs, and aim at harmonization and cross-border functionality.

- Co-fund large-scale demonstration pilots as part of a European testing agenda.

**Shared, connected and automated mobility services for people and goods**

- Establish a number living labs for early field operational testing and transport system integration of shared, automated and electric shuttles building on the results of EU-funded demonstration activities, involving regional stakeholders, businesses and operators. This measure shall also create coherence and transferability between the various sites.

**Socio-economic impacts and user/public acceptance**

- Conduct (and fund) commonly and jointly with the EC a study to explore the potential benefits and challenges of connected and automated driving and on-demand mobility on traffic system performance as well as energy consumption and emissions considering regional circumstances, sharing lessons learned and best practices and deriving recommendations for policy making on urban transport and spatial planning in order to avoid rebound effects.

**Human Factors**

- Fund research to explore opportunities of tele-operation to ensure safety of CAD in particularly complex and challenging situations, and run dedicated living labs to test, demonstrate and early deploy technology for it.

**Physical and digital infrastructure & secure connectivity**

- Establish living labs that showcase the feasibility and service quality of CAD higher levels of automation (SAE 3 and up) in complex situations such as mixed traffic, cross-border operation or urban scenarios due to availability of connectivity and physical and digital infrastructure and seamless integration into the traffic management system.

**Big data, artificial intelligence and their applications**

- Fund collaborative research on the application of “new” artificial intelligence concepts for CAD (including an appropriate risk assessment) and collaborative research on co-creating an ethical framework with the involvement of citizens, while deriving performance parameters and infrastructure support levels, and facilitating the sharing of ‘open’ modes needed to test and train the AI system.

## *8.4 For the Industry*

The industry is expected to commit to the joint objectives of European partnerships on connected and automated driving. For connected and automated driving this applies to any advisory functions on the coordination across sectors (e.g. automotive, electronics and telecom) or involving public and private stakeholders, such as expert groups, European Technology Platforms, Coordination and Support Actions and others. More specifically, as long as acting on pre-competitive grounds, companies can try to reach consensus within a sector and promote their joint understanding as a research need or an industry standard that supports harmonization. In terms of CAD that would be particularly useful for the definition of interfaces, business models and infrastructure needs in cooperation with road operators. In view of the assessments by the stakeholders involved in the edition of this roadmap, the following recommendations can be made towards industry:

**In Vehicle Enablers**

- Carry out evolutionary research and development on advanced perception, fail safe and cyber secure electronics, and decision making, and contribute to academia-led research projects funded by EC and MS, e.g. within the ECSEL JU.

**Vehicle Validation**

- Make technical assessments, provide interfaces and run large scale pilot actions for vehicle function validation. Provide input (e.g. data) necessary for the testing and validation of CAD functions and their safety for people both in the vehicle and its environment in cooperation with authorities and public organisations.

**Large Scale Demonstration Pilots to Enable Deployment**

- Setup coordination and support measures to build cross-sectorial networks that create business models and enable cross border functionality and harmonization at member states levels.

- Implement large-scale demonstration pilots for close to market technologies for highly automated passenger and freight vehicle services and related connectivity.

**Shared, connected and automated mobility services for people and goods**

- Develop vehicle and infrastructure technologies fit for the purpose of shared, connected and automated mobility services, considering e.g. user needs, business models or operational requirements.

**Socio-economic impacts and user/public acceptance**

- Foster public acceptance of CAD by applying human-centered design approaches for the development of new vehicles and operating models for CAD.

**Human Factors**

- Support harmonization of the design of human-machine interfaces (HMI) for the transition of vehicle control to the driver, road-user-vehicle interaction as well as tele-operation by agreeing on industry-wide standards.

**Physical and digital infrastructure & secure connectivity**

- Establish, test and validate cost-effective mechanisms for cyber security of CAVs building on a joint understanding of requirements and long-term stability and interoperability needs shared by OEMs and communication network providers.

## *8.5 EU-Member State Cooperation Needs and Potentials*

Even though the recommended measures made above can all be assigned to a responsible entity, many of them benefit from or even necessarily require a close collaboration between the Member States and with the involvement of the EU. Therefore, the following measures are proposed for EU-Member State collaborations:

- Commission an EU-funded study to define unified operational design domains (ODDs) taking into account various regional circumstances with the support of Member States road authorities.
- Establish a regular working group of the Member States regulators to harmonize vehicle validation procedures for CAD across Member States.
- Coordinate Research and Innovation (R&I) and testing activities in Europe, exploit synergies and identify possible fields for cooperation and develop a EU-wide testing agenda.
- Run cross-border demonstration between Member States to mutually recognize and accept testing rules to seamless functionality and early deployment of CAD.
- Exchange information on socio-economic, ethical and legal impacts of CAD and corresponding policy needs in order to understand and better address regional differences.
- Commonly conduct and fund a study to gain a common understanding of road safety expectations from CAD.
- Establish a binding code of conduct in anticipation of cyber security threats.
- Join the European CAD Stakeholder Forum to be established by the EC to gain knowledge of requirements for physical and digital infrastructure for CAD.
- Establish a joint agency to create and continuously update high-precision digital maps as a public good.
- Create a EU-wide large scale FOT Agenda and PPP cooperation to facilitate the deployment of CAD.

*Tab. 6: Recommended measures on the time line (blue: EC, orange: MS, green: Industry)*

| **In-vehicle Enablers** | | | |
|---|---|---|---|
| **Measures** | **Short** | **Medium** | **Long** |
| Fund R&I: perception, safe/secure electronics, decision making | EC | EC | |
| Co-Fund R&I: perception, s/s electronics, decision making | MS | MS | |
| Carry out evolutionary R&I; contribute to academia-led projects | I | I | |
| Launch standardization mandates: perception & cyber security | EC | EC | |
| Fund establishment of a watchdog for cyber secure CAD | | EC | |
| **Vehicle Validation** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Fund actions to reach various harmonization objectives | EC | EC | |
| Launch standardization mandate: testing & validation of CAD | EC | EC | |
| Support legislation policy: cross border testing, type approval | MS | MS | |
| Make assessments, provide interfaces and release data | I | I | I |
| Fund projects: virtual assessment, adaption of validation to AI | | EC | EC |
| **Large Scale Demonstration Pilots to Enable Deployment** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Foster setup of stakeholder platform on EU CAD testing agenda | EC | | |
| Fund FOTs, demos, living labs for CAD and connectivity | EC | | |
| Support demos of CAD bus/shuttle systems and goods traffic | EC | EC | |
| Provide necessary legal framework conditions and exceptions | MS | MS | |
| Build cross-sectorial networks on business models, cross border | I | I | |
| **Shared, connected and automated mobility services for people and goods** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Run an urban smart mobility and transport challenge | EC | | |
| Establish living labs on transport system integration of shuttles | | MS | |

| Measures | Short | Medium | Long |
|---|---|---|---|
| Develop fit-for-purpose vehicle and infrastructure technologies | | I | I |
| **Socio-economic impacts and user/public acceptance** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Setup expert group to assess ethical & liability issues of CAD | EC | | |
| Apply human-centered design approaches | I | | |
| Implement studies and debates on labor market effects of CAD | EC | EC | |
| Establish an observatory to assess societal impacts of mobility | EC | EC | |
| Commission EU-wide study on traffic system impacts of CAD | | MS | |
| **Human Factors** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Commission study on interaction between CAVs and road users | EC | EC | |
| Support harmonization of HMI by industry-wide standards | I | I | |
| Derive requirements in vehicle-user interaction / standardization | | EC | |
| Fund research to explore CAV tele-operation and run living labs | | MS | |
| **Physical and digital infrastructure & secure connectivity** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Establish EU CAD Stakeholder Forum to discuss PDI strategy | EC | | |
| Fund research to prepare the PDI ecosystem for CAD | EC | EC | EC |
| Establish, test, validate mechanisms for cyber security of CAVs | I | I | I |
| Mandate standardization of fail-operation at limited coverage | | EC | |
| Foster collaboration between traffic management centers in EU | | EC | EC |
| Establish living labs to showcase feasibility of CAD due to PDI | | MS | MS |
| **Big data, artificial intelligence and their applications** | | | |
| **Measures** | **Short** | **Medium** | **Long** |
| Fund collaborative research on data storage & sharing for CAD | EC | EC | |
| Fund collaborative research on artificial intelligence for CAD | MS | MS | |

# 9 Annex Road Transport

*Short summary of all actions per R&I initiative in each thematic field derived from the original action sheets as developed by the involved stakeholders. The content of the R&I initiatives and the information in instruments, timing and responsibilities as well as links is summarized in chapter 6, while a short description of the actions in given in chapter 7.*[54]

| #[55] | Thematic Field /Initiative / Action | Instr. | Timing | Impl. | Fund. |
|---|---|---|---|---|---|
| 1 | **In-Vehicle Enablers** | | | | |
| *1.1* | *Environment Perception* | | | | |
| 1.1.1 | Develop in vehicle perception systems | R&I | Short | I, A | I, EU/MS (ECSEL) |
| 1.1.3 *1.1.2* | Establish perception system performance standards for safety | Mandate | Short | ESO (I, A) | EU/MS |
| 1.1.2 *1.1.3* | Develop perception systems infrastructure based information | R&I | Medium | I, A | I, EU/MS |
| *1.2* | *Cyber-secure Electronics* | | | | |
| 1.2.1 | Define minimum-risk requirements for fail operation & cyber security | R&I | Short | I, A | I |
| 1.2.2 | Develop high performance computing on-board systems | R&I | Short | I, A | I, EU/MS (ECSEL) |
| 1.2.3 | Harmonize technologies to ensure lifetime proof cyber systems | R&I, C, Mandate | Short | I, A | I, EU/MS (ECSEL) |
| 1.2.4 | Establish central "watchdog" for cyber security of CAD systems | CSA | Medium | Multiple | EU |
| *1.3* | *On-Board Decision Making* | | | | |
| 1.3.1 | Define European Operation Design Domains (ODDs) for CAD | C | Short | I, A, ESO | EU |
| 1.3.2 | Develop decision making process considering regional differences | R&I | Medium | I, A | I, EU/MS |
| 1.3.3 | Support the implementation of ODDs in EU and beyond | CSA | Medium to long | I, A | EU |
| 2 | **Vehicle Validation** | | | | |
| 2.1 | *Vehicle Validation (Note: Requires 1.3.1)* | | | | |
| 2.1.1 | Define acceptable behaviour of AV functions in mixed traffic | R&I | Short | Multiple | EU, CEF |
| 2.1.2 *2.1.6* | Harmonize MS legislation to enable cross-border testing of CAD | C | Short | MS, I, A | EU |
| 2.1.3 *2.1.4* | Define standards for the testing and validation of CAD functions | Mandate | Short to medium | ESO, SDO, I, A | ESO, SDO budgets |
| 2.1.4 *2.1.5* | Prepare adaption of EU-level regu-lations & type approval to CAD | CSA, Policy | Short to medium | Multiple | EU |
| 2.1.5 *2.1.7a* | Create repository as database for sharing of test scenarios for | R&I, FOT/CSA | Short to long | Multiple + EU | Open |
| 2.1.6 | Develop virtual assessment tools | R&I | Short to | Multiple | EU |

[54] RIA: Research and Innovation Action, IA: Innovation Action, CSA: Coordination and Support Action, FOT: Field Operational Test, R&I: Research and Innovation, C: Coordination, I: Industry, A: Academia, L: Logistics Companies, O: Transport Operators, TM: Traffic Management Centers, ESO: European Standardisation Organizations, SDO: Standards Developing Organisations, CEF: Connecting Europe Facility, ECSEL: Joint Undertaking, EFTM: European Forum on Transport and Mobility (arising from Mobility4EU project), Conf: Conference, InCo: International Cooperation, RA: Road Authorities

[55] Original numbers from action sheets in italic

| | | | | | |
|---|---|---|---|---|---|
| *2.1.7b* | for CAD user protection | CSA | medium | | |
| 2.1.7 *2.1.3* | Adapt validation process to learning systems using AI, OTA updates | R&I Mandate | Medium to long | Multiple | EU |
| **3** | **Large Scale Demonstration Pilots to Enable Deployment** | | | | |
| *3.1* | *Passenger Vehicle Pilots* | | | | |
| 3.1.1 | Run L3 FOT and demonstrations in a diversity of real-life conditions | IA | Short | I, MS | I, EU/MS |
| 3.1.2 | Run L4 pilot addressing different use cases and complex traffic | IA | Short to long | I, MS | I, EU/MS |
| 3.1.4 *3.1.3* | Harmonize functionality and inter-operability for cross-border services | CSA, RIA | Short | Multiple | EU |
| 3.1.3 *3.1.4* | Create Living lab with PDI for safe pilots, evaluate requirements | IA | Short to medium | I | MS |
| *3.2* | *Commercial Vehicle Pilots* | | | | |
| 3.2.1 | Assess and foster readiness of logistics sector for CAD | CSA | Short | Multiple | EU |
| 3.2.2 *3.2.1* | Develop & demonstrate efficient and safe connected and automated heavy commercial vehicles in real logistics operations (open-road, hub-to-hub) | RIA | Short to medium / long | I, L | EU/MS |
| 3.2.3 *3.2.3* | Test mixed-traffic capabilities of CAD-HCV in semi-confined areas | IA | Short | I , L | EU |
| 3.2.4 *3.2.2* | Pilot open road truck platoons at short distances, on the fly, hub2hub | IA | Short to medium | I, L | EU |
| 3.2.5 *3.2.4* | Pre-deploy CAD-HCV for open-roads, urban areas, confined areas | IA | Medium | I, L | EU |
| 3.2.6 *3.2.5* | Demonstrate fully automated goods traffic (L5) towards open roads | IA | Medium to long | I | EU |
| *3.3* | *Automated e-Shuttle Pilots* | | | | |
| 3.3.1 | Assess and foster the CAD readiness of urban public transport | CSA | Short | Multiple | EU |
| 3.3.2 | Demonstrate L4/5 buses & shuttles incl. platoons in (sub-) urban areas | IA | Short to medium | I, O | I, O, EU/MS |
| 3.3.3 | Test automated BRT integrated with shared last mile shuttles | IA | Short to medium | I, O | I, O, EU/MS |
| 3.3.4 | Manage electric and automated bus fleet in the depot | IA | Short to medium | O | EU |
| *3.4* | *EU Road Testing Platform* | | | | |
| 3.4.1 | Setup a EU stakeholder platform to coordinate tests & define use cases | CSA | Short | Multiple | EU |
| 3.4.2 | Enable knowledge transfer, impact assessment and data exchange | CSA | Short | Multiple | EU |
| 3.4.3 | Monitor and evaluate efficiency and effectiveness of testing agenda | CSA | Medium | Multiple | EU |
| **4** | **Shared, connected and automated mobility services for people and goods** | | | | |
| *4.1* | *Shared Automated Mobility* | | | | |
| 4.1.1 | Define user needs regarding shared automated mobility | CSA | Short | Multiple | EU |
| 4.1.2 | Develop modeling and simulation for CAD-enabled mobility services | R&I, Prize | Short | Multiple | MS |
| 4.1.3 | Establish business models for shared and automated mobility | R&I | Short to medium | Multiple | EU, MS (KIC?) |
| 4.1.4 | Co-create inclusive, user-centric, and ubiquitous mobility services | R&I, CSA | Short to medium | Multiple | MS |
| 4.1.5 | Develop and demonstrate concepts for shared, automated mobility services for passengers and goods | IA, demo | Short to medium | Multiple | I, O, EC, MS, local |

| | | | | | |
|---|---|---|---|---|---|
| | delivery | | | | |
| 4.1.6 | Develop shared and automated vehicles for non-urban/rural areas | RIA, FOT | Medium to long | Multiple | EC, MS |
| *4.2* | *Mobility System Integration* | | | | |
| 4.2.1 | Enable seamless inter-operability across CAD digital platforms | IA | Short | I, A, O | EU |
| 4.2.2 | Pilot new automated bus tech and platoons in (sub) urban areas | RIA, CSA | Short to medium | I, O, Cities | EU |
| 4.2.3 | Integrate and plan for automated vehicles in mobility system | IA | Medium | Multiple | EU, MS |
| 4.2.4 | Develop concepts for providing services via automated platforms | IA, pilots | Medium to long | Multiple | EU, MS |
| *4.3* | *Fleet & Traffic Management* | | | | |
| 4.3.1 | Agree on targets, roles, roadmaps in mobility system to enable planning | CSA | Short | Multiple | EU, MS |
| 4.3.2 | Advance simulation, big-data, AI into EU network service innovation | R&I | Short | I, A | EU |
| 4.3.3 | Study consequences of CAD for fleet operations and mobility users | R&I | Medium to long | A, O | EU, MS |
| 4.3.4 | Define data to be exchanged to enrich traffic management | R&I, CSA | Medium | I, TM | EU |
| 4.3.5 | Develop and test CAD fleet and user services people and freight | R&I, FOT | Medium | O, cities | EU, MS |
| 4.3.6 | Assess total transport system effects including rebounds, new demands | R&I | Medium | O, cities | EU, MS |
| 4.3.7 | Develop and assess tools and technology for PDI for automation | R&I | Medium | I, A, O | EU |
| 4.3.8 | Testing feasibility of coordinated traffic management with CAD | IA, pilots, LL | Medium | Multiple | EU, MS |
| 4.3.9 | Establish remote control services for CAD e.g. in emergencies | R&I | Medium to long | Multiple | MS |
| **5** | **Socio-economic impacts and user/public acceptance** | | | | |
| *5.1* | *Societal Needs Analysis* | | | | |
| 5.1.1 | Determine safety level expected by passengers and road users | R&I | Short | Multiple | EU, MS |
| 5.1.2 | Assess expectations and needs e.g. in terms of accessibility design | R&I | Short | Multiple | EU, MS |
| 5.1.3 *5.1.5* | Explore ethical & liability aspects related to the introduction of CAD | R&I, C, Expert Grp | Short | Multiple | EU |
| 5.1.4 *5.1.7* | Recommend policies "making best use of automation in transport" | Conf | Short | Multiple | EU |
| 5.1.5 *5.1.8* | Harmonise indicators while safe-guarding diversity of user attitudes | R&I, C | Short | Multiple | EU, MS |
| 5.1.6 *5.1.4* | Study impacts of CAD and MaaS on spatial planning | CSA | Medium | Multiple | EU, MS |
| 5.1.7 *5.1.6* | Co-Create measures to enhance transport based on shared CAVs | R&I; C EFTM | Medium | Multiple | EU, MS |
| 5.1.8 *5.1.3* | Analyse impacts on driver attitude and behaviour, influencing safety | R&I | Medium | Multiple | EU, MS |
| *5.2* | *Social Impact Analysis* | | | | |
| 5.2.1 *5.2.4* | Assess boundary conditions and derive policy recommendations | R&I, Survey | Short | Multiple | EU, MS |
| 5.2.2 *5.2.5* | Study impacts of truck platooning from regulation point of view | R&I | Short | Multiple | EU, MS |
| 5.2.3 *5.2.1* | Explore socio-economic impacts of CAD for strategic decision making | R&I, Survey | Medium | Multiple | EU, MS |

| | | | | | |
|---|---|---|---|---|---|
| 5.2.4 *5.2.2* | Research benefits of CAD within transport system for society, cities | R&I, Survey | Medium | Multiple | EU, MS |
| 5.2.5 *5.2.3* | Assess long term impacts on trip planning and mobility behavior | R&I, FOT | Medium | Multiple | EU, MS |
| *5.3* | *Workforce Development* | | | | |
| 5.3.1 *5.3.4* | Assess skills for CAD engaging those who are affected | R&I, C Conf | Short to medium | Multiple | EU, MS |
| 5.3.2 | Assess impacts of CAD on existing labour market & educational system | R&I, C Conf | Short to medium | Multiple | EU, MS |
| 5.3.3 *5.3.1* | Recommend policies for labor market incentives and cost sharing | R&I, C Conf | Short | Multiple | EU, MS |
| 5.3.4 *5.3.3* | Facilitate workforce transition from manual to automated transport | R&I, Regulation | Short | Multiple | EU, MS |
| **6** | **Human Factors** | | | | |
| *6.1* | *Vehicle-User Interaction* | | | | |
| 6.1.1 | Analyse human factors challenges and develop on-board HMI | R&I, C | Short | Multiple | EU |
| 6.1.2 | Specifically design and harmonize HMI for CAV and future mobility | R&I, C, mandate | Medium | Multiple | EU |
| 6.1.3 | Set criteria for transition of control to driver and find appropriate HMI | R&I, C, InCo | Short to medium | Multiple | EU |
| 6.1.4 | Harmonize HMI testing and validation procedures | Mandate, InCo | Short to medium | I, MS | EU, MS |
| 6.1.5 | Define and adjust driver education training for CAV management | R&I, C, mandate | Short to medium | EU, MS | EU, MS |
| *6.2* | *Vehicle-Road User Communication* | | | | |
| 6.2.1 | Understand human-AV interaction (regional, cultural, gender, age) | R&I, C, InCo | Short to medium | Multiple | EU |
| 6.2.2 | Co-design and harmonize HMI of CAV for other road users | R&I, C, mandate | Short to medium | Multiple | EU, MS |
| 6.2.3 | Harmonize HMI testing and validation procedures | InCo, mandate | Short to medium | I, MS | EU |
| *6.3* | *Tele-Operation* | | | | |
| 6.3.1 | Understand work tasks and training needs of CAV tele-operators | R&I, C | Medium | I, TM, O | EU, MS |
| 6.3.2 | Design HMI interfaces for CAV tele-operation work places | R&I, CSA | Medium | Multiple | EU |
| 6.3.3 | Evaluate Human Factors of tele-operation of CAV | R&I | Medium | Multiple | EU |
| 6.3.4 | Define requirements and standards for CAV tele-operation | Study, regulation | Medium | I, O, MS | MS |
| **7** | **Physical and digital infrastructure & Secure connectivity** | | | | |
| *7.1* | *Physical / Digital Infrastructure* | | | | |
| 7.1.1 | Discuss strategy with OEMs, traffic managers, road operators, and users | EU CAD Forum | Short | Multiple | EU |
| 7.1.2 | Shape PDI ecosystem for cooperative, connected, automated driving | R&I | Short | I, TM, O | EU. MS |
| 7.1.3 *7.1.6* | Develop how CAV will impact PDI design and management | R&I | Short | Cities, TM | MS |
| 7.1.4 *7.1.3* | Advance infrastructure based sensing methods | R&I | Short to medium | I, TM | EU, MS |
| 7.1.5 *7.1.4* | Assess real-world performance of PDI for different use cases | LL, test areas | Medium | Multiple | MS, EU |
| 7.1.6 *7.1.5* | Optimize the provision and use of dyn/stat traffic-relevant | R&I | Medium to long | TM, O | EU |

| | | | | | |
|---|---|---|---|---|---|
| | information | | | | |
| *7.2* | *Traffic Management System (i.e. 7.3 in action sheets)* | | | | |
| 7.2.1 | Understand changes from human to software-based control | R&I | Short | TM, MS | EU |
| 7.2.2 | Define requirements for integrated CAD traffic management systems | R&I | Short | TM, MS | EU |
| 7.2.3 | Simulate and test integrated traffic, network and incident management | R&I | Medium | TM | EU |
| 7.2.4 | Integrate traffic management for CAD in real-world testing settings | Pilots, FOT | Medium | TM, O | MS |
| 7.2.5 | Implement CAD-specific traffic management systems | LL | Long | TM, O | MS |
| *7.3* | *Adequate Connectivity (i.e. 7.4 in action sheets)* | | | | |
| 7.3.1 | Ensure CAD fail-operation, degradation for limited network coverage | R&I | Short | I | EU |
| 7.3.2 | Standardize connectivity performance needed for safe, secure CAD | Mandate | Medium | ESO | EU |
| 7.3.3 | Prepare regulation of privacy and liability related issues of CAD | R&I | Medium to long | MS | MS |
| 7.3.4 | Design, validate mechanisms for cost-effective end-to-end security | R&I | Medium to long | Certification org | EU |
| *7.4* | *Cyber Security of Data (i.e. 7.5 in action sheets)* | | | | |
| 7.4.1 | Assess security requirements in a hybrid communication environment | R&I | Short | I, TM | EU |
| 7.4.2 | Analyse potentials for breaking security mechanisms of CAD | R&I | Short to medium | I, A | EU |
| 7.4.3 | Establish and validate cost-effective mechanisms for cyber security | C, FOT | Medium | RA | EU |
| 7.4.4 | Create and run international testbeds | R&I | Medium | TM, O, RA | EU |
| 7.4.5 | Develop procedures for CAD cyber security testing, validation, certific. | R&I, C | Short to medium | I | EU, MS |
| **8** | **Big data, Artificial Intelligence and their applications** | | | | |
| *8.1* | *Data Storage & Sharing* | | | | |
| 8.1.1 | Develop 'standard' model for data sharing focused on data value chain | R&I, C | Short | Multiple | EU, MS |
| 8.1.2 | Standardize data storage & enable it by providing reliable infrastructure | R&I, C | Short to medium | O, TM, I | EU, MS |
| 8.1.3 | Simulate and test the use of probe CAD vehicle, traffic, operation data | IA, FOT | Short to medium | O, TM | EU, MS |
| *8.2* | *Artificial Intelligence* | | | | |
| 8.2.1 *8.2.2* | Evaluate deep neural network-based algorithms | R&I, C | Short | I, A | I, EU |
| 8.2.2 *8.2.3* | Develop procedures for training and testing complex AI vehicle control | R&I, C | Short | I, A, ESO | EU, MS |
| 8.2.3 *8.2.4* | Develop ethical, moral framework for the use of AI in CAD | RIA | Short | I, A, EU / MS | EU, MS |
| 8.2.4 *8.2.1* | Develop AI concept, techniques, models to fulfill challenges of CAD | RIA | Short to medium | A | EU |

# PART II: RAILWAY TRANSPORT

## 1 Policy Targets and Objectives

*In this chapter, first the general objectives and challenges of connected and automated rail transport (CART) are introduced, followed by a summary of the European Union's goals in this domain as presented e.g. in the Europe on the Move policy package, and finally – referring to STRIA version 2017 - the special objectives of this implementation plan are explained. This is fundamental to the development of the strategic assessments in the further course of this document.*

### *1.1 Benefits and Challenges of Connected and Automated Rail Transport*

CART technologies are crucial enablers for railway system development. The potential benefits of CART include first of all, an increase of the capacity of the existing railway infrastructure. CART technologies could enable an increase in the availability of the network due to increased reliability and a reduced requirement (in number and duration) for maintenance possessions. Moreover, if properly implemented, a considerable reduction in energy consumption of vehicles and systems could be reached. All in all, it could all lead to to a reduction of investment, operation and maintenance costs of infrastructure and rolling stock.

### *1.2 European Commission's Policy Objectives*

Energy Union and Decarbonisation

The rail sector aims at keeping its competitive advantage (to other surface transport modes) of being the most environmentally friendly mode of transport and plans that[56]:

- By 2030 the European railways will reduce their specific average CO2 emissions from train operation by 50% compared with the base year 1990; measured per passenger-km (passenger service) and gross ton-km (freight service).

- In addition, by 2030 the European railways will not exceed the total CO2 emission level from train operation in absolute terms even with projected traffic growth compared to base year 1990.

The European railways strive towards carbon-free train operation by 2050 and provide society with a climate neutral transport alternative. Moreover, stronger legislative measures will be required to introduce the incentives necessary for using environment-friendly modes of transport, supported by CART technologies. Therefore, the investment of the rail sector to transport

[56] Source: CER-UIC environmental strategy

decarbonisation, including through energy-efficient technologies, and in dealing with other mega-trends such as urbanization and demographic change should be met by other well-defined policies and targets for a modal shift to rail - for both passengers and freight.

Growth and Competitiveness

The 2011 Transport White Paper sets the following targets through to 2050 with regard to competitiveness:

- 30% of road traffic over 300 km should shift to other modes such as rail or waterborne transport by 2050;
- By 2050 a European high-speed rail network should be complete. The length of the existing high-speed rail network should be tripled by 2030 and a dense railway network maintained in all Member States;
- By 2050 the majority of medium-distance passenger transport should be by rail.

The competition among the various transport modes and their speed of development is often controlled and regulated by large industries active in all modes. The level playing field between the various modes should be better addressed by policy measures.

Number of passengers for rail services, such as in urban and suburban rail services, is rapidly growing, reaching almost 9 billion passengers for rail and 7,7 billion passengers for light rail train (LRT) and trams annually. This trend shows the importance of rail transport in Europe and the need for proper financing as a motivator and enabler of the further development and optimisation of this mode of transport. Growth and competitiveness of the rail sector are important drivers for further development in each of the rail transport market segments. Modern CART technologies will support strengthening competitiveness of the rail sector in relation to other modes.

The CART roadmap aims therefore to increase the ability of the European rail supply sector to compete globally. The CART roadmap supports the Resolution on the competitiveness of the European rail supply industry adopted by the European Parliament Industry Committee in June 2016.[57] With 400.000 employees the European rail industry creates more than 1 million direct and 1,2 million indirect jobs within EU and accounts to 46% of the world’s total railway supply industry market.

Safety and Other related issues

[57] 2015/2887(RSP)

A high level of safety is a primary objective of rail transport. CART solutions are perceived as enablers to reduce or eliminate human factor errors, increase secure connectivity and thus further reduce the low number of incidents and accidents on European networks. This can be achieved with the help of CART technologies in the following areas:

- Full supervision modes of European Railway Traffic Management System (ERTMS) / European Train Control System (ETCS) to ensure that trains will not pass the end of movement authority and that the train speed and its integrity will be continuously monitored;

- Automatic Train Operation (ATO) to reduce human factor errors by eliminating need for train driver;

- CART technologies for new maintenance concepts (like condition-based or predictive maintenance) including asset monitoring, to eliminate incidents or accidents caused by deteriorating condition of assets (both on-board and trackside)

- In the long term, a fully integrated railway that will provide the basis for full autonomous systems, enabled by new technologies such as artificial intelligence, super and Quantum computing, next generations of telecoms and positioning.

The ERTMS offers the improvement of safety related functionalities at level crossings, like automatic adjustment of Movement Authority for trains depending on the status of level crossing clearance.

Moreover, the application of Constant Warning Time for road users and innovative connectivity to ITS solutions could contribute for improving safety on level crossings. Although various road car navigation systems have already included warnings that the car is approaching a level crossing, there is no easy possibility to enforce stop or lower speed of the car, in case that a train is near the level crossing. This functionality can be added in the future automated or autonomous cars, as well as any other portable media/mobility system used by citizens. In that case warnings could also be extended to other road users.

# 2 State of the Art

*This chapter first introduces the terminologies of grades of automation that are used in the following parts of the document. Afterwards, the European state of the art in connected and automated rail transport is explained, referring to technical and non-technical dimensions, and building on the assessments by the involved stakeholders. This shall serve as a foundation for identifying the gap of challenges and opportunities towards the objectives outlined before, in the following chapters.*

## *2.1 Terminology*

There are 5 Grades of Automation (GoA) of trains, according to standard IEC/TR 62267-2:2011[58]- Railway applications - Automated urban guided transport (AUGT) - Safety requirements. These 5 grades have been initially defined for urban rail (e.g. metro) and are also applicable for long distance railway and freight.

- GoA 0 is on-sight train operation, similar to a tram running in street traffic;
- GoA 1 is manual train operation where a train driver controls starting and stopping, operation of doors and handling of emergencies or sudden diversions;
- GoA 2 is semi-automatic train operation (STO) where starting and stopping is automated, but a driver operates the doors, drives the train if needed and handles emergencies;
- GoA 3 is driverless train operation (DTO) where starting and stopping are automated but a train attendant operates the doors and drives the train in case of emergencies;
- GoA 4 is unattended train operation (UTO) where starting and stopping, operation of doors and handling of emergencies are fully automated without any on-train staff.

The descriptions of these levels and the related roles of the automated system as well as the human driver are summarized in figure 5.

[58] International Electrotechnical Commission technical report. webstore.iec.ch/publication/6680

| Grade of Automation | Train Operation | Setting train in motion | Driving and stopping train | Door closure | Operation in event of disruption |
|---|---|---|---|---|---|
| GoA 1 | ATP with Driver | Driver | Driver | Driver | Driver |
| GoA 2 | ATP and ATO with Driver | Driver / Automatic | Automatic | Driver | Driver |
| GoA 3 | Driverless (DTO) | Automatic | Automatic | Attendant / Automatic | Attendant |
| GoA 4 | Unattended (UTO) | Automatic | Automatic | Automatic | Automatic |

ATP: Automatic Train Protection
ATO: Automatic Train Operation
DTO: Driverless Train Operation
UTO: Unattended Train Operation

Figure 5: Grades of automation for railway applications

## *2.2 Holistic Description of the State of the Art*

Rail transport can be classified into several line categories including high speed, mainline, regional, urban (metro, tramways, light rail), and freight line.

Even though CART technologies are already well embedded in some selected European market segments of rail transport, in others the uptake of these technologies is still slow and yet to come.

On mainline and regional railways, in 1991-1993 the GoA 2 operation on mainlines was pioneered in the Czech Republic where it was implemented on one locomotive and two Electric Multiple Units (EMUs) on a 50 km long double-track line. Since then a fully commercial GoA 2 operation gradually evolved to around 350 equipped locomotives and passenger units running on almost 3 000 km of double and single-track lines. Consequently, in 2011 a pilot operation of GoA 2 ATO connected to ETCS ATP was carried out in the Czech Republic. Recently GoA2 operation has been started also in England (Thameslink).

The technological progress in the nineties led to the situation that in other market segments of rail-bound transport (light rail, tramway, metro, suburban rail, main lines) CART technologies based on common standards were developed and deployed, like mass transit Communication Based Train Control (CBTC) systems or ETCS and GSM-R. In addition, more recent innovations for connected and automated rail are now driven by ERTMS, such as ATO, ETCS Level 3, future communication systems and satellite technology.

The highest state of the art grade of automation 4 – a fully automated driverless rail systems - exists today in metro systems. Besides the automatic operation based on moving block principle (creating safe distances between moving vehicles in real-time), the GoA 4 system is responsible for door closing control, for dealing with obstacles on tracks during the journey and for coping with emergencies. It should be well noted that this highest GoA level was mainly introduced on newly constructed metro lines, in an isolated environment, not accessible for third parties. Moreover, applied solutions on test sites were not standardised and expensive.

The rail sector recognises that the digital railway will prepare the sector for the general digitalisation of the economy as it is already ongoing for other modes of transport. Major European railway undertakings and infrastructure managers, including DB AG, SNCF and Network Rail, initiated digitalisation action plans to the benefit of the final user. The major rail stakeholders from all over Europe, including supply industries, operators, infrastructure managers, research centres and universities have agreed to work closely together on digital innovations within the Shift2Rail Joint Undertaking's programme, ensuring that national and multinational initiatives also are brought within a common umbrella to leverage research, innovation and development investments.

At the same time, railway competitiveness compared to other modes of transport depends, to a larger extent, on economies of scale in deploying new technologies and an overall acceptation of standardisation of the technical requirements and operational rules at European level.

Despite the gradual uptake of the technology, the European rail landscape remains very diversified and is characterised by various layers of safety and legacy operational principles, obsolete technical solutions as well as long life-cycle stages. As a result, the process of implementing CART technologies in rail is progressing slowly, jeopardising the competitiveness of the railway sector.

There are several documents addressing directly and indirectly aspects of automation and connectivity, such as the Strategic Rail Research and Innovation Agenda (SRRIA) together with related roadmaps for various parts of rail-bound systems, and the Master Plan and Multi-Annual Action Plan of the Shift2Rail Joint Undertaking.

The existing state of the art with regard to sector vision, related research and innovation policy measures and the ongoing Shift2Rail JU activities creates a good reference point for an automated and connected roadmap for the part of rail-bound transport.

## 3 Hurdles and Opportunities

*This chapter summarizes the most relevant barriers and opportunities for implementation of connected and automated rail transport in Europe. This overview shall serve as basis for building the plan of initiatives and actions in the following chapters.*

The deployment of higher grades of automation and other CART related solutions in railways are **hindered by**:

- economic life cycle cost (LCC) considerations: differences in assessment when the existing systems should be replaced;
- migration strategy and coexistence of hybrid systems during transition;
- diversity of existing technical standards and operational principles per country;
- the need to continuously guarantee adequate safety and security levels, not impacted by transitions towards new technologies;
- shorter life-cycles of new technologies confronted with long life cycles of assets and related issues of backwards compatibility;
- the institutionalized separation of management and regulations between infrastructure and rolling stock, which impedes the overall railway system view and results in a complicated investment environment;
- limits of connectivity using the existing GSM-R standard.

Main **research gaps and the deployment barriers** include, but are not limited to:

- slow pace of implementation of European policy support measures and new standardized solutions;
- a high number and diversity of national technical and operational rules;
- highly fragmented picture of railway regulations and (CART) technical solutions among European countries;
- different stages of development of automated rail solutions in various European countries;
- focus on technical interoperability, without proper attention to operational interoperability, which preserve the existing national operational rules and negatively impact cross-border operations;
- culture of ex post coordination instead of ex ante cooperation;

- the relatively high CAPEX/ OPEX cost of rail-bounded system;
- long life cycles of existing systems hinder uptake of rapidly developed new technologies;
- risk exposure of railways on sustainability of their investments in new technologies, due to the high amortisation costs and short life cycles (often upgrades) but on the other hand rather long development cycles and approval processes to agree on new harmonised solutions;
- limited availability of commercial off-the-shelf (COTS) based solutions, as market is answering Railway Undertakings / Infrastructure Managers (RU/IM) ad hoc specifications (largely based on national rules but not only) clearly countered only by specialized and, consequently, expensive CART products;
- lack of vision on target architecture supporting soft and short-term deployment of CART solutions;
- concerns about emerging cyber security and resilient communication aspects, which could slow down and higher the costs of the deployment of CART solutions;
- insufficient number of skilled resources and lacking unification of training systems and technical culture;
- uncertain user acceptance in autonomous passenger train operation;
- uncertain driver acceptance and potential resistance to the necessary change of driver tasks and skill development

The implementation of connected and automated rail transport in Europe brings many **opportunities**, such as:

- support to the European-wide implementation of ERTMS;
- key contribution to the digitalization of European railway system (e.g. future rail mobile communication system, digital twin of railway infrastructure, cybersecurity);
- emerging new digital technologies could deliver breaking-through innovations to the railway sector and create new services and business cases;
- emergence of innovative data driven services enabled by new data streams combined with advanced AI techniques can contribute to improvement of the competitiveness and overall performance of the railway system;
- effort saving and innovation time cycle shortening resulting from the knowledge transfer between transport modes;

- integration of other rail-bound modes (metro, tramway) and their respective stakeholders in the ongoing European research under Shift2Rail can accommodate connected and automated rail transport in the urban environment and fully integrate it in Mobility as a Service (MaaS) concept;

- improved user experience in multimodal transport;

- user’s needs will stimulate to strengthen relationships between general CART developments, caused by policy trends, and the practical needs, foreseen benefits or existing constraints of customers.

# 4 Roadmaps and Plans

*In this chapter, the roadmap approach and recommendations developed by the European Technology Platform ERRAC and the Joint Undertaking Shift2Rail are summarized. Their findings are directly taken into account in the drafting of the action sheets for the plan at hand.*

## *4.1 ERRAC and Strategic Rail Research and Innovation Agenda (SRRIA)*

The European Rail Research Advisory Council (ERRAC) was established in 2001 with the ambitious goal of creating a single European platform with the competence and capability to help revitalise the European rail sector and make it more competitive, by fostering increased innovation and guiding and monitoring research efforts at European level.[59] The SRRIA published in 2014 specifically addresses the European efforts required for research and innovation to achieve the ambitious goal set out by the European Commission in the Transport White Paper published in 2011. It recognizes the challenge brought by automated train driving operations across research themes.

## *4.2 ERRAC Rail 2050 Vision*

The Rail 2050 Vision of ERRAC originally published in 2018 supports the acceleration of the deployment of CART solutions and a wider implementation of higher grades of automation. The Vision is that rail will be the backbone of the European transport system which integrates and maximises the benefits brought by each mode. This document[60] envisages that by 2050 rail vehicles, infrastructure (including stations) and command and control systems will be fully digitalised and will be networked components of the "internet of things" concept. Each element will also be endowed with local artificial intelligence which will give it the ability to perform goal-oriented tasks with a high degree of autonomy. It is also envisaged that combinations of autonomous, intelligent and highly responsive vehicles will be able to communicate with each other and with the intelligent infrastructure, ensuring safe and reliable operations, while running closer together and contributing to reduce life-cycle costs substantially. This constitutes a successful deployment of the next generation of the traffic management systems such as ERTMS and CBTC.

In the future, distributed operation management of autonomous trains will allow for adaptive and accurate adjustments to transport demand patterns, dramatically increasing the capacity and flexibility of the rail transport system for all types of line: urban, high speed, freight, regional and mainline. Fully automated train operation, autonomous train and intelligent remote-controlled systems will guarantee an unprecedented level of safety. Autonomous operations will also enable new types of mobility on rail, such as self-operated light pods/shuttles providing seamless interconnection across infrastructures.

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[59] http://errac.org/wp-content/uploads/2014/11/CER_FosterRailReport.pdf
[60] http://www.errac.org/wp-content/uploads/2018/01/122017_ERRAC-RAIL-2050.pdf

The emergence of enabling technologies, such as artificial intelligence, the "internet of things", robotics, vehicle-to-vehicle and vehicle-to-infrastructure communications, autonomous driving and block-chain will provide a wide range of possibilities for innovation in the rail system and to change the way it operates, supporting improvements in rail based logistics and mobility in the short run.

### *4.3 Shift2Rail*

The Shift2Rail Joint Undertaking (S2R JU) is the first European rail initiative to seek focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions.[61]

The work conducted within the Shift2Rail framework is structured around five asset-specific Innovation Programmes (IPs), covering all the different structural (technical) and functional (process) subsystems of the rail system. In particular, Innovation Programme 2 (IP2) "Advanced traffic management and control systems" addresses directly and indirectly several aspects of automation and connectivity. The other IPs, which focus on rolling stock, infrastructure, customer-facing IT and freight, also feature significant levels of automation and connectivity development within a systems approach to railway technical development.

Already today the on-going R&I efforts under Shift2Rail are providing the building block, which is necessary to create a CART system transformation, responding to the following objectives:

- Improving rail system performance by moving to open, harmonized and interoperable technologies:
    - automatic driving;
    - communication;
    - intelligent measuring;
    - monitoring and information systems;
    - shift to multimodal traffic management systems;
    - financial transactions/ticketing;
    - tracking and tracing vehicles and goods in real time.
- Sustain and further develop the railway sector robustness by increasing capacity by automation and digitalization;

[61] shift2rail.org/about-shift2rail/

- Increase rail attractiveness (passenger & freight) by improving connectivity, passenger information and experience, freight data handling, achieving shorter travel times;
- Improve competitiveness by reducing lifecycle operational costs e.g. by automation of asset management systems, intelligent maintenance and operational processes and tools through whole life cycle;
- Sustain and further develop the environmental friendliness to become carbon-free transport mode by 2050 and provide society with a climate neutral transport alternative, partly by improving technical characteristics like energy efficiency due to higher automation;
- Effectively leverage new technologies such as digitalization, next generation of telecoms and positioning, new materials, big data, energy storage and efficiency;
- Reduce other negative externalities (e.g. noise);
- Further increase safety.

Aspects of automation and connectivity play a crucial role in realising these objectives and challenges.

Fostering the inclusion of metro’s and trams in the overall S2R R&I Command Control and Communication measures would facilitate achieving the above objectives on a larger scale within the future smart cities. Emerging new mobility concepts using the rail environment could contribute to increased multi-modal integration to deliver the backbone of synchromobility.

In conclusion, the impact of CART technologies on policy goals will stay limited without an integrated system approach to deployment.

Thus, the existing state of the art and ongoing R&I efforts under the Shift2Rail JU, and the recently published technology & innovation roadmaps of ERRAC shall be used as a baseline to establish a dedicated roadmap related to automation & connectivity in the rail domain.

# 5 Programmes and Projects

*The purpose of this chapter is to draw the landscape of the European Union's and Member States' previous and current actions in terms of programmes and projects for innovation in connected and automated rail transport.*

## *5.1 European Commission*

Shift2Rail projects[62]

A key challenge for Shift2Rail IP2 is to enhance the advanced traffic management and control systems without impacting the ERTMS at its core, and where appropriate and necessary, to provide backwards compatibility to protect investments both in mainline and urban railways. Projects are organised around the following Technical Demonstrators (TDs), covering all the R&I areas indicated in the Shift2Rail Master Plan: Smart, fail-safe communications and positioning systems; Traffic Management Evolution; Automation; Moving block and train integrity; Smart procurement and testing; Virtual coupling and Cyber security.

As part of IP5 dedicated to freight, The 'Autonomous train operation' (TD 5.6) aims to actively pursue the objective of Autonomous Train Operation (ATO), realised progressively until 2030, for mainline freight operation and the underlying operations, in order to increase the railway's competitiveness and to achieve operational efficiency gains and optimised resource utilisation. Also, the end points of rail freight are in focus, the developments and automation of terminals is necessary for the CART.

Horizon 2020

- FOSTER-RAIL - The EU funded FOSTER-RAIL project was launched in order to support the work of the European Rail Research Advisory Council (ERRAC) to the European Commission. It addressed the challenge to strengthen and support research and innovation cooperation strategies in the European rail sector. Co-operation and co-ordination across Europe holds significant opportunity for Freight Competitiveness, with technology and innovation needed for novel approaches to new freight services such as increased use of automation.

- SETRIS - The H2020 EC funded SETRIS project offered the opportunity for ERRAC to foster the implementation of the priorities defined in FOSTER-RAIL and further developed/updated in SETRIS, and take a step further by collaborating with other transport ETPs to build the future integrated transport system. This project has developed a list of recommendations, some of them addressing connected and automated rail transport.

[62] http://projects.shift2rail.org/s2r_projects.aspx

## *5.2 EU Member States*

Current activities of European Member States in support of innovation for connected and automated driving can be briefly summarized according to the reports of the involved Member States representatives as follows:

Austria

Austria has prepared a 25-kilometer long stretch of railway for the testing of autonomous trains in a realistic environment. The Ministry of Traffic supports the project with 16 million Euros. The line is situated between Oberwart in the Austrian state of Burgenland and Friedberg in Stiermarken. It passes eight stations, twelve railway crossings and a 524-meter long tunnel offering a variety of environmental factors that make possible to test different situations that can occur during a train journey, in the context of automating this train ride. The main aim is to test and research the digital communication between locomotive and its environment.

Belgium

The company Alstom is prominently present in Belgium with its worldwide expertise center about ERTMS technology (located in Charleroi). In the framework of the RIA strategy of the Walloon region, Alstom developed different projects (some of them with Infrabel, the Belgian railway network operator) around ATO issues.

France

French rail operator SNCF has launched an ambitious program called Tech4Rail/Programme ATO aiming at developing the future of connected and automated rail transport. This program includes three key projects led by SNCF and Railenium with the support of national railway industry and research stakeholders contributing to the development and deployment of connected and automated rail transport.

- TC-Rail (2017-2021): Development and full-scale demonstration in real conditions and mixed railway traffic environment of remote train driving.

- Autonomous Train (2018-2023): Development and full-scale demonstration in real conditions and mixed railway traffic environment of highly automated and autonomous trains (from GoA2 to GoA4) for freight and passengers.

Germany

- Deutsche Bahn (DB), is reportedly working on bringing autonomous technology to its vehicles by as early as 2021. A 30km section of track in the German state of Saxony near the Czech border has been constructed for this purpose and tests are now underway. The trains being tested in this project are making use of cameras and other collision-detection technologies in order to avoid accidents.

- Deutsche Bahn (DB) and Siemens are currently developing digital operations for the S-Bahn in the city of Hamburg. Highly automatic operations are planned along the 23 km line between the stations 'Berliner Tor' und 'Bergedorf/Aumühle'. In October 2021, when Hamburg is host to the ITS World Congress, four digitally controlled trains will serve this line[63].

- In a cooperative project between industry and academia, a fully automatic shunting locomotive is being tested and demonstrated during normal operations at the Munich North marshalling yard. The aim is to reach series production readiness by 2021[64].

- 5G-ConnectedMobility project in Bavaria creates a dedicated network infrastructure and application environment for 5G analysis and testing in real-time for Vehicle-to-vehicle, Vehicle-to-infrastructure, and Railway-to-infrastructure. Railway use cases include video-based control and automation of the traction mode.

- An autonomous tramway was successfully demonstrated in Postdam in September 2018.The experimental tramway operated by local operator ViP has been equipped with a range of sensors integrated with operating commands (including traction and braking) and onboard artificial intelligence to respond to lineside signals and halt at each stop. At this stage, a driver is still present in the tramway to supervise the operation, and intervene when required.

The Netherlands

Dutch infrastructure manager ProRail is developing test facilities for the implementation of Automated Train Operation (ATO) systems in the Netherlands. It plans to invest time and money, help organise relevant activities and provide test facilities for trains equipped with ATO systems. The Betuweroute is a dedicated freight line, constructed in 2007 with the aim to shift freight traffic from road to rail. Apart from the technical aspects of this line, its purpose is suited for the implementation of ATO systems.

Poland

The INNOSBZ sectorial program is aimed at increasing the competitiveness and innovativeness of the Polish sector of unmanned systems production on the global market in the perspective of 2023/2026.

The thematic areas on which the activities of the Program are focused are:

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[63] www.deutschebahn.com/de/presse/pressestart_zentrales_uebersicht/Deutsche-Bahn-und-Siemens-entwickeln-digitalisierten-Betrieb-bei-der-S-Bahn-Hamburg--3183666

[64] www.lok-report.de/news/deutschland/industrie/item/6083-cna-sonderpreis-2018-fuer-vollautomatische-abdruecklokomotive-val2020.html

GROUP I:

- Unmanned aerial vehicles
- Unmanned land platforms (including rail mode)
- Unmanned waterborne platforms

GROUP II:

- Subsystems, subassemblies and technologies for unmanned platforms
- Industrial applications for the mission of crisis management support, protection of critical infrastructure, environmental protection and industrial supervision

Spain

Spain currently contemplates initiatives tending to favor the development of the connected train and the automation of the railway operation; from the institutional sphere, based on their experience in metropolitan areas, as well as participating in projects of high technological scope such as Hyperloop.

Spanish institutional context:

The Spanish R&D Strategy for the period 2013-2020 (2018), in *Challenge 4: Sustainable, Intelligent, Connected and Integrated Transportation*, which is a priority activity in terms of R&D: The design and manufacture of autonomous transport vehicles and remotely manned systems including the testing of technologies and components for more efficient, clean, safe, connected and autonomous vehicles and the development of security systems (active and passive) and connectivity linked to the various degrees of automation of vehicles including the railway industry.

The Spanish Railway Technology Platform, PTFE, in its document "SWOT Analysis and Scientific and Technological Priorities and Innovation of the Spanish Railway Sector" Vision 2050, June 2017 has clearly defined the challenge: Automate existing lines through the implementation of UTO systems (without driver) adapting the rolling stock, as well as safety facilities, control centers and operational procedures that allow automated operation. To this end, it has defined the following Strategic Actions for 2020: (a) Definition of future command and operation centers for the operation of automated railway lines without a driver, marking generic premises on ergonomic, operational, functional and technological factors; (b) Definition of the process of certification of autonomous lines without driver: Risk analysis and preparation of the safety plans of the subsystems and the operation, maintenance and reception procedures that guarantee the integral safety of the system.

The Spanish Ministry of Public Works and Transport has launched a Transport & Infrastructure Innovation Plan (2017) that develops the innovation strategy covers rail automation.

- Spain has a broad experience in the automation of the operation in metropolitan and urban areas. The first automatic train experience in Spain was implemented in Barcelona and it entered into service in 2010. The Line 9 of the Barcelona Metro is an automatic subway metropolitan rail line that currently has 24 stations in operation. The service is operated by the Metropolitan Transport of Barcelona (TMB). This metro line is expected to have 52 stations (20 of them connected to other means of transport) and 47,8 km in length in the future. The rolling stock material belong to 9000 Alstom series making use of ATC-S system of automatic driving that allows the circulation of the railways without driver with an MTO level of autonomy MTO (Manless train operation).

- In addition, Spain is also making relevant efforts to support the "Hyperloop" that can be considered a new transport mode fully autonomous. The Ministry of Transport (including ADIF and Renfe), the Ministry of Science, Innovation and Universities and private investors are supporting "Hyperloop" projects in the following areas: the establishment of a research center, building 2Km test site to optimize the vehicle leading to a substantial cost reduction and safer working pressures for the passengers, etc.

# 6 The Research and Innovation Initiatives

*In this chapter, the structure of the implementation plan, consisting of thematic areas, R&I initiatives and actions is explained, the content is presented, and assessments of timing, priority, responsibility, links and accelerators are made at the level of initiatives. This shall serve as a high-level, comparative analysis of the inputs identified and prioritized by the involved stakeholders though the action sheets.*

## *6.1 Structure of the Roadmap*

The assessments for the roadmap are structured into three key elements, being thematic areas, R&I initiatives and actions.

Thematic areas are the division of themes for research and innovation in field of connected and automated rail transport. In total 9 thematic areas have been proposed.

R&I initiatives are concrete activities and undertakings to be implemented by stakeholders in order to achieve the European Union's goals of connected and automated rail transport. They are described in terms of objectives, state of the art challenges as well as impacts. There are several initiatives per thematic area.

Actions describe in sequence the content of all activities that have to implemented within each of the R&I initiatives. They are summarized in action sheets (one per initiative).

## *6.2 Contents of the R&I Initiatives*

1. Rolling stock enablers for remote control of train operation and autonomous train operation

   This thematic area focuses on the necessary upgrades of the rolling stock to enable autonomous train operation. At the technology level, there is a need to develop technologies for obstacle detection, trackside signal detection and hybridized train positioning and integrate them with on-board intelligence. In addition, railway systems need to be enhanced to improve safety at level-crossings in the perspective of CART solutions for both rail and road transport, to monitor train integrity and to enable remote train operations.

   1.1. Reliable environment perception to identify all external hazards and to detect trackside signals enabling on-board decision-making intelligence

   1.2. Reliable train positioning

   1.3. Enhanced Control-Command system

   1.4. Enhanced Train Control and Management System

2. Environment and operational monitoring

   In addition to the core driving tasks, train drivers have additional tasks to perform such as monitoring of the railway infrastructure and other trains, and monitoring of the internal train environment with great attention on preventive maintenance and incident detection. In order to manage the transition to complete automation, these tasks have to be gradually shifted away from drivers with the use of driver advisory systems and on-board decision intelligence.

   2.1. Reliable external and internal environment perception (outside ATO)

   2.2. Enhanced Decision and Advisory Support

3. Large scale demonstrations to enable EU-wide deployment

   Field operational tests and demonstrations in real-life operational conditions are a key step towards EU-wide deployment of CART for rail transport by validating requirements and collecting data for impact assessment based on real freight and passenger railway use cases. Considering the complexity of running such tests, especially in cross-border environment, there is a need to set up a European testing agenda with the development of a common testing and deployment framework.

   3.1. Pilots of autonomous passenger trains in real conditions and mixed railway traffic environment

3.2. Pilots of autonomous freight trains in real conditions and mixed railway traffic environment, including the terminals/end-to-end transportation

3.3. EU-wide common experiment/testing agenda and common framework on testing and deployment

4. Railway network information, management, maintenance and control

CART in rail transport is expected to deliver significant benefits that can contribute to improved performance of the overall railway system. Therefore, it is important to transform opportunities offered by automated train operation to improve railway infrastructure and rolling stock asset management, smart traffic management, multimodality with other (automated) transport modes, competitiveness of rail freight and user experience.

4.1. Smart maintenance and asset management

4.2. Logistics on demand, smart terminals and increased last mile handling

4.3. Smart traffic management

4.4. User experience and multimodality

4.5. Management of interactions with passengers for safe and secure operation

5. Socio-economic and environmental impacts – User/public acceptance

A comprehensive impact assessment of connected and automated train for freight and passengers is crucial to develop common understanding, both for strategic decision making and railway operations, on the benefits for safety, network capacity, multimodality, user acceptance, environmental impact and competitiveness. Special attention should be paid to social impact on jobs and development of skills to manage digitalization of railway.

5.1. Comprehensive impact assessment of connected and automated passenger train

5.2. Comprehensive impact assessment of connected and automated freight train

6. Human factors

Human factors need to be addressed at two levels, inside and outside the connected and automated train. During the transition from partial automated train operation (GoA2) to fully autonomous train (GoA4), driver tasks will be transformed, and it will require the development of suitable

Human-Machine-Interface (HMI) and associated driver training schemes. In parallel, interactions between highly automated/fully autonomous trains and users/workers (in the train, at stations, at level-crossings, along the tracks) need to be addressed to preserve safety and security.

6.1. Driver tasks for remote train operation and highly automated train operation

6.2. Communication and interaction between automated passenger train / tramway and users / workers

7. Physical and digital infrastructure & secure connectivity

Development and deployment of CART for rail transport goes hand in hand with the digitalization of railway system. Three main building blocks have to be considered: (a) the development of the digital twin of the railway infrastructure, (b) the development of the future rail mobile communication system based on hybrid communication technologies and (c) the cyber security layer that protect physical and digital railway system from cyber threats.

7.1. Development of digital twin of railway infrastructure

7.2. Fast, safe, reliable, affordable and high-capacity connectivity between all parts of the rail system and its environment

7.3. Cyber security for connected and automated railway system

8. Big data, Artificial Intelligence and their applications

The feasibility of CART for rail transport depends significantly on the capacity to manage huge amount of data generated by multiple devices (e.g. on-board sensors) and integrate them with different artificial intelligence (AI) solutions to overcome complexity of autonomous train operation. New data streams combined with advanced AI techniques create opportunities for innovative data driven services that can contribute to improve competitiveness and overall performance of railway system.

8.1. Create more value from data in connected and automated railway system

8.2. Further development and use of AI in connected and automated railway system

9. Safety

Highest safety level is key for the success of connected and automated train deployment. The introduction of new advanced technologies (e.g. sensors, telecom, AI) in the railway system require the revision of testing and approval procedures, the development of new methodology to asses safety levels and the potential revision of safety integrity levels (SIL) and certification procedures. These efforts need to be addressed on a European scale and supported by an appropriate regulatory framework.

9.1. EU-wide testing procedures for connected and automated train

9.2. EU-wide safety assessment program for connected and automated train

### *6.3 Assessments of the Initiatives: Priority, Timing, Responsibility, Links*

Prior to an in-depth consideration of the actions defined for each R&I initiative in the next chapter, here, a comparative assessment of the initiatives themselves is made. This analysis is based on voting and discussions among the most relevant stakeholders, who expressed their interest to participate.

In order to classify initiatives by their priority in terms of importance of implementation, a priority ranking of these initiatives is proposed (table 7). The rail system is based on technologies and operations that, due to their long lifecycle, legacy and national rules, have largely reached their limits in meeting final users' (passengers, shippers, etc.) needs and expectations. Hence, the initiatives listed here below appear almost all as "high", although there might be different needs in the different railway segments.

Further, a distinction on the timeframe of initiative application is proposed: short-, mid- and long term (table 8). However, most actions, independently of their timeframe, would in any case need to start at about same time, as they are interdependent from each other and mutually reinforce technological advancement in a constant exchange of research results.

Finally, for each of the initiatives, the implementation instrument and the funding source are indicated (table 9). The decision is based on the nature of each initiative and the assessment of most efficient instrument.

The action plan for connected and automated train has to be regarded in systematic approach, all initiatives and actions identified in a course this roadmap are interlinked and dependent on each other. In order to have a comprehensive view on most crucial interlinks, table 10 provides a harmonized overview of these initiatives mutually giving or requiring inputs from each other.

*Tab. 7: Priority ranking of initiatives*

| Priority | # | Short Title of Initiative |
|---|---|---|
| High | 1.1 | Environment perception (ATO) |
| High | 1.2 | Reliable train positioning |
| High | 1.3 | Enhanced Control-Command system |
| Medium | 1.4 | Enhanced Train Control and Management System |
| Medium | 2.1 | External and internal environment perception |
| Medium | 2.2 | Decision and Advisory Support |
| High | 3.1 | Pilots of passenger trains |
| High | 3.2 | Pilots of freight trains |
| High | 3.3 | Experiment/testing agenda |
| Medium | 4.1 | Maintenance and asset management |
| Medium | 4.2 | Logistics on demand |
| Medium | 4.3 | Smart traffic management |
| Low | 4.4 | User experience and multimodality |
| Medium | 4.5 | Interactions with passengers |
| High | 5.1 | Impact assessment for passenger train |
| High | 5.2 | Impact assessment for freight train |
| High | 6.1 | Driver tasks |
| High | 6.2 | Communication and interactions with users |
| High | 7.1 | Digital twin |
| High | 7.2 | Connectivity |
| High | 7.3 | Cybersecurity |
| Medium | 8.1 | Create more value from data |
| High | 8.2 | Development and use of AI |
| High | 9.1 | Testing procedures |
| High | 9.2 | Safety assessment program |

*Tab. 8: Timing per Initiative*

*The timing of the various initiatives indicates when first results from research and innovations actions would be available. Actions on a short term are expected to deliver by 2025, medium term by 2030 and long term - beyond 2030.*

| # | Short Title of Initiative | Short Term | Mid Term | Long Term |
|---|---|---|---|---|
| 1.1 | Environment perception (ATO) | X | | |
| 1.2 | Reliable train positioning | X | | |
| 1.3 | Enhanced Control-Command system | X | X | X |
| 1.4 | Enhanced Train Control and Management System | | X | X |
| 2.1 | External and internal environment perception | X | X | |
| 2.2 | Decision and Advisory Support | X | X | |
| 3.1 | Pilots of passenger trains | | X | |
| 3.2 | Pilots of freight trains | X | X | |
| 3.3 | Experiment/testing agenda | X | X | |
| 4.1 | Maintenance and asset management | X | X | |
| 4.2 | Logistics on demand | | X | |
| 4.3 | Smart traffic management | X | X | |
| 4.4 | User experience and multimodality | | X | X |
| 4.5 | Interactions with passengers | | X | |
| 5.1 | Impact assessment for passenger train | | X | |
| 5.2 | Impact assessment for freight train | X | X | |
| 6.1 | Driver tasks | X | X | |
| 6.2 | Communication and interactions with users | | X | |
| 7.1 | Digital twin | X | | |
| 7.2 | Connectivity | X | X | |
| 7.3 | Cyber security | X | | |
| 8.1 | Create more value from data | X | X | |
| 8.2 | Development and use of AI | X | X | X |
| 9.1 | Testing procedures | X | X | |
| 9.2 | Safety assessment program | | X | |

*Tab. 9: Responsibilities per Initiative*

| # | Short Title of Initiative | Implementation | Funding |
|---|---|---|---|
| 1.1 | Environment perception (ATO) | I, O, A | EC/S2R |
| 1.2 | Reliable train positioning | I, O, IM, IMA | EC/S2R |
| 1.3 | Enhanced Control-Command system | I, O, IM, A, ERA | EC/S2R |
| 1.4 | Enhanced Train Control and Management System | I, O, IM, A, ESO, ERA | EC/S2R |
| 2.1 | External and internal environment perception | I, O, IM, A | EC/S2R |
| 2.2 | Decision and Advisory Support | I, O, IM, A | EC/S2R |
| 3.1 | Pilots of passenger trains | O, I, IM, A, MS, CI | EC/S2R, MS, CEF, ERDF, EFSI |
| 3.2 | Pilots of freight trains | O, I, IM, A, L, MS | EC/S2R, MS, CEF, ERDF, EFSI |
| 3.3 | Experiment/testing agenda | O, IM, I, MS, A, ESO ERA NSA | EC/S2R, MS, CEF, ERDF, EFSI |
| 4.1 | Maintenance and asset management | O, IM, I, A | EC/S2R |
| 4.2 | Logistics on demand | O, IM, L, I, A | EC/S2R, EFSI |
| 4.3 | Smart traffic management | O, IM, I, A, ESO | EC/S2R |
| 4.4 | User experience and multimodality | I, O, IM, A, ESO | EC/S2R |
| 4.5 | Interactions with passengers | I, O, IM, A | EC/S2R |
| 5.1 | Impact assessment for passenger train | O, IM, I, A, MS, CI, U | EC/S2R, MS |
| 5.2 | Impact assessment for freight train | O, IM, I, L, A, MS | EC/S2R, MS |
| 6.1 | Driver tasks | O, I, A, MS | EC/S2R, MS |
| 6.2 | Communication and interactions with users | O, IM, I, A, U | EC/S2R |
| 7.1 | Digital twin | IM, I, A, ESO | EC/S2R |
| 7.2 | Connectivity | I, O, IM, A, ESO, ERA | EC/S2R |
| 7.3 | Cybersecurity | I, O, IM, A, MS, ERA, ESO | EC/S2R, MS |
| 8.1 | Create more value from data | O, IM, I, L, A | EC/S2R |
| 8.2 | Development and use of AI | I, O, IM, A, MS | EC/S2R, MS |
| 9.1 | Testing procedures | I, O, IM, A, MS, ERA | EC/S2R, MS |
| 9.2 | Safety assessment program | O, I, IM, A, MS, ERA, NSA | EC/S2R, MS |

I: Industry, A: Academia, L: Logistics Companies, O: Railway Operators, IM: Infrastructure Managers, ESO: ECropean Standardization Organizations, SDO: Standards Developing Organizations, ERA: European Union Agency for Railways, NSA: National Safety Authorities, EU: European Commission, MS: Member States, CI: Cities, U: Users, CEF: Connecting Europe Facility, ERDF: European Regional Development Fund, EFSI: European Fund for Strategic Investments, S2R: Shift2Rail JU, HPC PPP: High Performance Computing PPP

*Tab. 10: Links between Initiatives*

| | (Column) Requires input from… (line) | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Given Input to…. | 1.1 | 1.2 | 1.3 | 1.4 | 2.1 | 2.2 | 3.1 | 3.2 | 3.3 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 5.1 | 5.2 | 6.1 | 6.2 | 7.1 | 7.2 | 7.3 | 8.1 | 8.2 | 9.1 | 9.2 |
| 1.1 | | | | | | | X | X | | | | | | | | | | | | | | X | X | | |
| 1.2 | | | | | | | X | X | | | | | | | | | | | | | | | X | | |
| 1.3 | | | | | | | X | X | | | | | | | | | | | | | | | X | | |
| 1.4 | | | | | | | | | | | | X | | | | | | | | | | | | | |
| 2.1 | | | | | | | X | X | | | | | | | | | | | | | | X | | | |
| 2.2 | | | | | | | X | X | | | | | | | | | | | | | | | | | |
| 3.1 | | | | | | | | | | | | | | | X | | | | | | | | | | X |
| 3.2 | | | | | | | | | | | | | | | | X | | | | | | | | | X |
| 3.3 | | | | | | | X | X | | | | | | | | | | | | | | | | | |
| 4.1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.2 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.4 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5.1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5.2 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6.1 | | | | X | | | X | X | | | | | | | | | | | | | | | | | |
| 6.2 | | | | | | | | | | | | | | X | | | | | | | | | | | |
| 7.1 | | | | | | | X | X | | | | | | | | | | | | | | | | | |
| 7.2 | | | X | X | | | X | X | | X | | X | X | X | | | | | | | | X | | | |
| 7.3 | | | | X | | X | X | X | | | | | | | | | | | | | | | | | |
| 8.1 | | | | | | | | | | X | | | | | | | | | | | | | | | |
| 8.2 | X | | | | X | | X | X | | | | | | | | | | | | | | | | | |
| 9.1 | X | X | X | X | | | X | X | | | | | | | | | | | | | | | X | | |
| 9.2 | | | | | | | X | X | | | | | | | | | X | | | | | | | | |

# 7 Action Plan

*In this chapter, a comprehensive plan based on action plan assessments is presented, taking into account timings and interlinks of the proposed actions and initiatives. A particular emphasis is put on opportunities for accelerating the innovation process through agile methodology, complementarity and coherence.*

## *7.1 Comprehensive Implementation Plan*

As a result of integration of all above mentioned aspects, a comprehensive implementation plan is presented in table 11. It summarizes instruments, timing, implementation instruments and funding body for each of initiatives across 9 thematic areas.

*Table 11: Action Plan[65]*

| # | Thematic Field /Initiative / Action | Instr. | Timing | Impl. | Fund. |
|---|---|---|---|---|---|
| **1** | **Rolling stock enablers for remote control of train operation and autonomous train operation** | | | | |
| 1.1 | Develop reliable environment perception to identify all external hazards and to detect trackside signals enabling on-board decision-making intelligence | RIA, IA, P, C | Short | I, O, A | EC/S2R |
| 1.2 | Develop reliable train positioning | IA, P, C | Short | I, O, IM, A | EC/S2R |
| 1.3 | Develop enhanced Control-Command system | RIA, IA, P, S | Short/Mid | I, O, IM, A, ERA | EC/S2R |
| 1.4 | Develop enhanced Train Control and Management System | RIA, IA, P, S | Mid | I, O, IM, A, ESO, ERA | EC/S2R |
| **2** | **Environment and operational monitoring** | | | | |
| 2.1 | Develop reliable external and internal environment perception (outside ATO) | RIA, IA, P | Short/Mid | I, O, IM, A | EC/S2R |
| 2.2 | Develop enhanced Decision and Advisory Support | RIA, IA, P | Short/Mid | I, O, IM, A | EC/S2R |
| **3** | **Large scale demonstrations to enable EU-wide deployment** | | | | |
| 3.1 | Run pilots of autonomous passenger trains in real | IA/FOT, P, C | Mid | O, I, IM, A, MS, | EC/S2R, MS, |

[65] RIA: Research and Innovation Action, IA: Innovation Action, CSA: Coordination and Support Action, FOT: Field Operational Test, R&I: Research and Innovation, C: Coordination, P: Procurement, S: Standardization, INCO: International Cooperation, I: Industry, A: Academia, L: Logistics Companies, O: Railway Operators, IM: Infrastructure Managers, ESO: European Standardization Organizations, SDO: Standards Developing Organizations, CEF: Connecting Europe Facility, ERDF: European Regional Development Fund, EFSI: European Fund for Strategic Investments, S2R: Shift2Rail, HPC PPP: High Performance Computing PPP, ERA: European Union Agency for Railways, NSA: National Safety Authorities, EC: European Commission, MS: Member States, CI : Cities, U: Users

| | | | | | |
|---|---|---|---|---|---|
| | conditions and mixed railway traffic environment | Policy INCO | | CI | CEF, ERDF, EFSI |
| 3.2 | Run pilots of autonomous freight trains in real conditions and mixed railway traffic environment | IA/FOT, P, C Policy INCO | Mid | O, I, IM, A, L, MS | EC/S2R, MS, CEF, ERDF, EFSI |
| 3.3 | Define EU-wide common experiment/testing agenda and common framework on testing and deployment | CSA, P, S Policy INCO | Short/Mid | O, IM, I, MS, A, ESO ERA NSA | EC/S2R, MS, CEF, ERDF, EFSI |
| **4** | **Railway network information, management, maintenance and control** | | | | |
| 4.1 | Develop mart maintenance and asset management | RIA, IA, P INCO | Short/Mid | O, IM, I, A | EC/S2R |
| 4.2 | Adapt logistics on demand and increased last mile handling | RIA, IA, P | Mid | O, IM, L, I, A | EC/S2R, EFSI |
| 4.3 | Enhance smart traffic management | RIA, IA, P, C, S | Mid | O, IM, I, A, ESO | EC/S2R |
| 4.4 | Improve user experience and multimodality | RIA, IA, P, S Policy | Mid/Long | I, O, IM, A, ESO | EC/S2R |
| 4.4 | Study interactions with passengers for safe and secure operation | RIA, IA, P, C | Mid | I, O, IM, A | EC/S2R |
| **5** | **Socio-economic and environmental impacts –User/public acceptance** | | | | |
| 5.1 | Assess impacts of connected and automated passenger train | RIA, P, C INCO | Mid | O, IM, I, A, MS, CI, U | EC/S2R, MS |
| 5.2 | Assess impacts of connected and automated freight train | RIA, P, C INCO | Mid | O, IM, I, L, A, MS | EC/S2R, MS |
| **6** | **Human factors** | | | | |
| 6.1 | Study driver tasks for remote and highly automated train operation | RIA, C Policy | Short/Mid | O, I, A, MS | EC/S2R, MS |
| 6.2 | Analyse communication and interaction between automated passenger train / tramway and users / workers | RIA | Mid | O, IM, I, A, U | EC/S2R |
| **7** | **Physical and digital infrastructure & secure connectivity** | | | | |
| 7.1 | Develop digital twin of railway infrastructure | RIA, S | Short | IM, I, A, ESO | EC/S2R |

| | | | | | |
|---|---|---|---|---|---|
| 7.2 | Develop fast, safe, reliable, affordable and high-capacity connectivity between all parts of the rail system and its environment | RIA, IA, P, C, S INCO | Short/mid | I, O, IM, A, ESO, ERA | EC/S2R |
| 7.3 | Adapt cyber security for connected and automated railway system | RIA, IA, P, C, S Policy INCO | Short | I, O, IM, A, MS, ERA, ESO | EC/S2R, MS |
| **8** | **Big data, Artificial Intelligence and their applications** | | | | |
| 8.1 | Create more value from data in connected and automated railway system | RIA, IA, P, C | Short/Mid | O, IM, I, L, A | EC/S2R |
| 8.2 | Further develop and use AI in connected and automated railway system | RIA, IA, P, C | Short/Mid/Long | I, O, IM, A, MS | EC/S2R, MS |
| **9** | **Safety** | | | | |
| 9.1 | Define EU-wide testing procedures for connected and automated train | IA, P, S | Short/Mid | I, O, IM, A, MS, ERA | EC/S2R, MS |
| 9.2 | Define EU-wide safety assessment program for connected and automated train | RIA, CSA Policy | Mid | O, I, IM, A, MS, ERA, NSA | EC/S2R, MS |

# 8 Conclusions and Recommendations

*In this chapter, the action plan laid out in the previous chapter is translated into lists of recommendations for the various stakeholders involved, particularly the European Commission, the Member States and the industry.*

## *8.1 General actions of high relevance and urgency*

Following the sector stakeholder consultation, the work focused on identifying the key actions and of the crucial relevance for developing a Connected and Automated railway system. The systemic approach of the exercise is fundamental, and each of the currently proposed actions represents a necessary piece of the overall puzzle to successfully progress in CART development.

All proposed actions rely on close cooperation between the different railway stakeholders. Therefore, the highest level of commitment is required from all actors to join efforts in supporting the following recommendations.

## *8.2 For the European Commission*

General recommendations for the European Commission are:

- Cover both fundamental and high-risk applied research as well as EU-wide deployment in the context of overall railway system through a comprehensive framework and dedicated structure. This, of course, taking into consideration existing legacy systems and building on research work performed by Shift2Rail related to CART;

- Foster innovation take up towards EU-wide deployment;

- Foster the development of European interoperable solutions, through knowledge sharing, harmonization and strategy development among stakeholders under a coherent framework, including international cooperation;

- Support the use of procurement schemes to accelerate innovation and deployment;

- Address European interoperability and safety through a system architecture approach (currently developed in Shift2Rail) and using all available instruments, including standardization and regulation;

- Explore any guided transport systems that would contribute to CART;

- Foster involvement of cities and regions to address urban and regional implementation of CART;

- Encourage cross fertilization between the different transport modes on technology enablers and horizontal issues to benefit from technology transfers and to avoid duplication of efforts and interoperability gaps.

According to the nine thematic areas, more specific recommendations have been defined where the European Commission can take leadership to ensure effective implementation of the roadmap:

**Rolling stock enablers for remote control of train operation and autonomous train operation**

- Fund research on technology enablers (e.g. advanced perception, reliable positioning, train integrity monitoring) and railway system enablers (e.g. enhanced control command system, train control and management system);

- Fund research on new regulation approaches of the railway system;

- Fund CSA on establishing cross-fertilization with other transport modes regarding common technology enablers;

- Address standardization and potential regulation evolution needs on control command, train control and management and road-railway communications to ensure interoperability.

**Environment and operational monitoring**

- Fund research to manage transition from driver decision and advisory support to complete automation, including external and internal environment perception.

- Large scale demonstrations to enable EU-wide deployment

- Fund field operational tests, demonstrations and living labs, including cross-border environment for close to market technologies in automated passenger and freight rail systems aiming to validate requirements and collect data for impact assessment;

- Foster the setup of an EU railway stakeholder platform to define a European testing agenda and develop a common testing and evaluation framework (currently discussion ongoing in Shift2Rail).

**Railway network information, management, maintenance and control**

- Fund research on how connected and automated rail can contribute to improve performance of overall railway system, including asset management, logistics, traffic management, interactions with passengers and user experience;

- Foster multimodality by addressing interconnections with other (automated) transport modes.

**Socio-economic and environmental impacts – User/public acceptance**

- Fund a comprehensive impact assessment (safety, socio-economic, environment, employment, skills, user acceptance) of connected and automated rail transport for passenger and freight taking advantage of large amount of data collected through field operational tests;

- Explore impacts of CART on jobs and public opinion in general through a dialogue with trade unions, consumer and passenger associations;

- Fund CSA to foster cooperation with other connected and automated transport modes in terms of methodology and side impacts on multimodality.

**Human factors**

- Fund research to prepare the transition towards highly automated train operation by adapting driver HMI and developing new driver training schemes;

- Setup an expert group representing the different transport modes to study the interactions of users with automated transport.

**Physical and digital infrastructure & secure connectivity**

- Integrate needs identified for connected and automated train into the overall strategy for the digitalization of European railway system and the Shift2Rail system approach;

- Fund research to develop the necessary interoperable digital twin of railway infrastructure for connected and automated train operation, in close cooperation with other use cases (e.g. Building Information Modelling);

- Fund research for the development of the future rail mobile communication system and foster cooperation with road transport to integrate communication needs specific to connected and automated train into a comprehensive multimodal connected mobility development and deployment strategy, including cybersecurity and standardization aspects.

**Big data, Artificial Intelligence and their applications**

- Fund research on data storage, mining, sharing and analytics to support the development of new data-driven services that can contribute to improve performance of railway system;

- Fund research on the development and integration of advanced IA solutions to overcome complexity of autonomous train operation and encourage cooperation with other transport modes using similar IA techniques.

**Safety**

- Fund research to develop EU-wide testing procedures for connected and automated train with proper integration of new techniques (e.g. AI) and technologies (e.g. sensors, communication);

- Establish an expert group to define an EU-wide safety assessment program for connected and automated train that would investigate potential revision of safety integrity levels (SIL) and needs for harmonized regulatory framework.

## *8.3 For the Member States*

General recommendations for the European Member States are:

- Address regional differences through harmonising efforts for interoperability and safety;

- Foster involvement of cities and regions to address urban and regional implementation of CART;

- Integrate national/local R&I initiatives into European-wide R&I strategy, and vice versa;

- Foster bilateral cooperation between EU Member States to support cross-border initiatives;

- Align R&I investment and funding programmes between Member States and European programmes;

- Support and promote European standardisation efforts in international organisations;

- Facilitate knowledge and innovation transfer and exchange of results between national and European R&I activities by adopting harmonised methodologies.

According to the nine thematic areas, more specific recommendations have been defined where the European Member States can take leadership to ensure effective implementation of the roadmap:

**Rolling stock enablers for remote control of train operation and autonomous train operation**

- Co-fund research on technology enablers (e.g. advanced perception, reliable positioning) and railway system enablers (e.g. enhanced control command system, train control, management of operations and management system).

**Environment and operational monitoring**

- Co-fund research on environment and operational monitoring that take into consideration national peculiarities of railway infrastructure end train operation.
- Large scale demonstrations to enable EU-wide deployment
- Facilitate the establishment of living labs by adopting the necessary legal framework conditions and exceptions for large scale and cross-border demonstrations of connected and automated rail transport.
- Railway network information, management, maintenance and control
- Establish living labs to experiment innovative services enabled/supported by connectivity and automation that contribute to improve performance of rail transport system.

**Socio-economic and environmental impacts – User/public acceptance**

- Fund studies to assess impacts of connected and automated rail transport considering regional/national peculiarities, contribute to knowledge sharing and exchange of best practices, and promote benefits to national/local stakeholders.

**Human factors**

- Support initiatives on potential revision of driver training schemes and certification with active participation of rail transport authorities.

**Physical and digital infrastructure & secure connectivity**

- Actively contribute to harmonization efforts in the development of digital railway infrastructure and secure connectivity.

**Big data, Artificial Intelligence and their applications**

- Fund research on the application and the validation of big data and artificial intelligence for connected and automated rail transport by fostering knowledge transfer between automated transport modes and experience gained from other sectors.

**Safety**

- Engage national railway safety agencies in the development of EU-wide regulatory framework for safety assessment of connected and automated rail transport.

### *8.4 For the Industry*

General recommendations for the European Industry that include both railway operators and supply industry are:

- Demonstrate commitment for active contribution to existing organisations (e.g. Shift2Rail, ERRAC) to reach consensus in pre-competitive research activities that are strategically supported by the European Union to reach system targets goals;

- Support development and adoption of industry standards leading to harmonization and economies of scale;

- Take leadership in international cooperation to promote EU collaborative research results and achievements.

- According to the nine thematic areas, more specific recommendations have been defined where the European Industry can take leadership to ensure effective implementation of the roadmap:

**Rolling stock enablers for remote control of train operation and autonomous train operation**

- Collaborate with academia and other automated transport modes to develop technology and product roadmaps that will steer efforts in delivering enablers.

**Environment and operational monitoring**

- Share knowledge on all tasks carried out by drivers to monitor railway environment and train operation.

**Large scale demonstrations to enable EU-wide deployment**

- Facilitate access to experimental data collected during demonstrations by academic partners.

**Railway network information, management, maintenance and control**

- Open access to living labs to SMEs and startups to stimulate innovation and accelerate deployment with shorter development cycle.

**Socio-economic and environmental impacts – User/public acceptance**

- Share enough knowledge on business models to ensure proper economic impact assessment.

**Human factors**

- Support harmonization of HMI for train driver in the context of remote control and highly automated rail driving.

**Physical and digital infrastructure & secure connectivity**

- Establish cost and time effective collaboration with other sectors (e.g. other transport modes, telecom) to deliver appropriate industry standards.

**Big data, Artificial Intelligence and their applications**

- Initiate horizontal actions with other sectors to accelerate knowledge transfer on the application of big data and artificial intelligence and their potential limits for connected and automated rail transport.

**Safety**

- Contribute to the development and the adoption of harmonized testing procedures that integrate new technologies (e.g. artificial intelligence) and new risks (e.g. cyber security).

# PART III: WATERBORNE TRANSPORT

## 1 Policy Targets and Objectives

*This chapter addresses the policy targets and objectives of EC and the industry at large as well as specific objects identified during the STRIA process.*

### *1.1 General objectives*

Digitalization will transform maritime and inland waterway transport in near future and will be a powerful push towards new innovations. The early adopters will get clear benefits, sometimes by being the first to enter the market, thus being able to lead the development of technologies and standards for the market as well as having increased opportunities to receive public support towards their first of a kind deployment. They will be able to exploit new business models and new skills.

The potential benefits of connected and automated waterborne transport include primarily:

- Increasing waterborne safety, reducing accidents by offering assistance to humans and limiting the possibilities of human error (providing for example better situational awareness and decision support systems) and ensuring that the most effective actions are taken in the event of an emergency.

- Provide more efficient support from shore infrastructure such as VTS and ports for increased safety and efficiency in congested waters.

- Increased cost efficiency of waterborne transport through more efficient operations (mainly through a decrease in energy usage and use of pooled services) and savings in investment costs (achieved by moving activities to shore and larger centres).

- Decrease in emissions due to higher operational efficiency and a drive towards cleaner technologies better suited to connected and automated technologies.

- Facilitate the increased use of waterborne transport and as a result contribute to the reduction of greenhouse gas emissions from intermodal logistic chains and the decongestion of land transport infrastructure.

- Provide means for truly intermodal transport via increased sharing of data and real time information on a grand new scale.

- Enabling radical new business models which can be serviced by automated and connected vessels.

The full potential can be unlocked when completely automated and connected operations are in place throughout the logistics chain.

For international shipping, the IMO (International Maritime Organisation) is undertaking a scoping exercise of the regulatory implications of maritime autonomous surface ships (MASS) vessels[66] where the human factor, is an important element within the discussion. In this respect, the human factor includes at least the level of role/responsibility, change in the governance and, at the organisational level, education and training, new skills for seafarers and equipment suppliers, social resistance etc. Ethical issues including the human factor, should therefore be kept in mind, when considering automated and connected waterborne transport. The human factor also includes interactions with humans within environments where both manned and unmanned transport may operate in the future.

### *1.2 European Commission's policy objectives*

In May 2017, the European Commission published the first mobility package which includes a series of legislative and non-legislative initiatives specifically targeting transport. One of the documents prepared was the Commission Staff Working Document, which focused on the definition of a Strategic Transport Research and Innovation Agenda (STRIA)[67]. This document presents a forward-looking agenda for research and innovation in transport, where connected and automated transport (CAT) is one of 7 priorities.

Transport is one of the sectors that hold the greatest potential for contributing to the Energy Union goals regarding decarbonisation, greater efficiency and competitiveness. The Transport White Paper[68] cites several decarbonisation objectives that are relevant for waterborne transport. The European Commission initiated STRIA for this reason. The STRIA exercise focusses on the development and deployment of low-carbon transport technology solutions encompassing at the same time digitalization, safety, security and other relevant aspects.

In line with the Transport White Paper, 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050. This will reduce overall carbon emissions from transport. Automated waterborne vessels as well as automated infrastructure and equipment can enable completely new transport solutions that can achieve this objective.

Increased connectivity and automation are megatrends that will affect mobility in the future. Substantial benefits are expected from the increased use of connectivity and automation technologies in all modes of transport and they are instrumental for the cross-modal integration of transport. Increasing safety is

[66] http://www.imo.org/en/MediaCentre/MeetingSummaries/MSC/Pages/MSC-98th-session.aspx
[67] SWD (2017) 223 'Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package. Brussels, 31.5.2017
[68] White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Brussels, 28.3.2011. COM (2011) 144

often the main driver for deploying CAT, because limiting or removing the human element from vehicle operation and providing them with assistance in the form of increased automation, can have large effects on lowering collision rates and their severity[69].

The other main driver for introduction of CAT is competitiveness. CAT is crucial for the ability of the European transport related industry to preserve and consolidate its global competitiveness. Application of CAT can also contribute to the Energy Union targets for GHG emissions and energy efficiency, through decreased energy usage, and to European primary transportation policy objectives, as well as productivity, through e.g. efficiency of traffic flows and improved infrastructure capacity[70].

### *1.3 Objectives of this document*

With its third mobility package, the European Commission particularly proposes to develop a strategic plan of R&I actions and to better coordinate national and multinational funding programs on connected and automated transport. In this regard, the European Commission intends to develop, in close cooperation with the Member States and industry stakeholders, roadmaps such as this which include concrete action plans for short, medium and long-term research and innovation initiatives as indicated in chapter 23. Compared to the 2017 STRIA document on CAT, this document aims to identify initiatives and actions which are more tangible and specific in terms of content, timing and responsibility.

[69] SWD (2017) 223 'Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package. Brussels, 31.5.2017 ec.europa.eu/programmes/horizon2020/en/news/connected-and-automated-transport-expert-group-report

[70] Ibid.

# 2 State of the Art

Waterborne transport has been the first application of wireless connectivity with Marconi making the first shore to ship radio transmission in 1899. Its potential to improve safety soon became evident following the Titanic disaster in 1912, where a radio distress signal saved many lives. Automated navigation has also been first applied to shipping with first self-steering systems being deployed in the early 1900's. Increasingly sophisticated and satellite-based versions of these technologies are now essential elements of all modern ships. Furthermore, satellite based global voice data and internet is available and deployed within the majority of the world's shipping. However, costs remain comparatively high and data speeds can be low and unreliable.

The role of connectivity and automation in waterborne transport is generally less publicly visible than developments in other transport modes which are closer to the consumer market. However, Europe is a leader in connected and automated waterborne transport technology and deployment, and needs to continuously innovate to maintain this competitive position against fierce global competition.

The need for a common vocabulary and agreed definitions is discussed, including the lack of agreed upon automation levels etc. Afterwards, the European state of the art in connected and automated waterborne traffic is explained. This shall serve as a foundation for identifying the gap of challenges and opportunities towards the objectives outlined before, in the following chapters.

## *2.1 Terminology*

Regarding the terminology for automated and connected solutions, there is still much confusion in the waterborne industries. There are no commonly agreed definitions including levels of autonomy, such as the other transport modes have, and different actors use otherwise different terminology. The IMO regulatory exercise talks about **Maritime Autonomous Surface Ships (MASS)**, and that term is used at least on the maritime side. According to IMO, MASS is defined as a ship which, to a varying degree, can operate independent of human interaction[71]. Many of the documents also talk about autonomous and remotely operated ships. Some research and industry organizations have published documents on the terminology and it will be very shortly reviewed here.

According to the UK Maritime Industry Code of Practice[72]: *Manned* means that a vessel or a craft is controlled by operators on board. In the future this might only mean that there is a crew on board, but the control is somewhere else. The code of practice uses the term *unmanned* for partially autonomous vessels, but it is quite possible to have a vessel capable of autonomous operations to be

[71] IMO MSC 100/WP.8
[72] Maritime UK: Being a Responsible Industry, Maritime Autonomous Surface Ships UK Code of Practice, A Voluntary Code, Version 2.0, November 2018

manned. The code aimed to determine levels of autonomy with this terminology, but as we will soon show, that is rather difficult for waterborne vessels.

The NFAS (Norwegian Forum for Autonomous Ships) in their definitions for autonomous merchant ships[73], define *autonomous ships* as a ship with some form of autonomy. They define *automation* as the process, often computerized, that implement a specific and predetermined method to execute certain operations without a human controlling it. *Fully autonomous ship* according to them is also an unmanned ship with fully autonomous control functions. So, in these definitions too, the term autonomy is determined by manning. NFAS defines *remote control* as the ship being remotely controlled from a shore control centre. Although this is a rather accepted definition, in a connected world, the remote control can happen from elsewhere too in the future.

For the purposes of this document, we adhere to the NFAS definition on *automation*[74]. When we refer to *remote control*, it means that a vessel is controlled from somewhere other than the vessel itself. By *autonomous* we mean self-governing or independent, which is how the dictionary defines autonomy. *Fully autonomous* means the highest level of autonomy (which levels have not been yet agreed upon for waterborne traffic, as is explained next). *Unmanned* in this report means without manning.

In their IMO paper[75], the Finnish flag state argued that none of the current proposals for **levels of autonomy** should be used. Based on a workshop carried out with several of the suppliers for automated waterborne systems, held 20.4.2018 in Helsinki, the problems for waterborne traffic lies in the fact that many of the proposals are based on the levels of autonomy from e.g. the automotive industry. Those levels of autonomy would apply mainly to navigational autonomy and navigation systems are only one set of systems on board a ship. Waterborne traffic also has the added dimension of remote control, which may or may not be related to the technical autonomy levels. Also, as the examples in previous paragraphs showed, autonomy is often mixed with manning, although the two might not at all be related. A vessel can be fully autonomous and still have manning for various reasons. There is also the matter whether decision making is local or connected, which adds another dimension to the problem. When for example propulsions systems will become more autonomous in the future, there comes the question of how long the system should work independently to be autonomous. The autonomy levels discussion also often forgets to consider the autonomy of other waterborne systems, such as IWT or harbours. Figure 6 below demonstrates the issue.

[73] NFAS Norwegian Forum for Autonomous Ships: Definitions for Autonomous Merchant Ships, 10.10.2017
[74] Automation is quite common around the ship and when something is automated, it is done without human control (unmanned). However, this should not be confused with autonomy of ship systems. These are two different things.
[75] IMO MSC 99/5/6

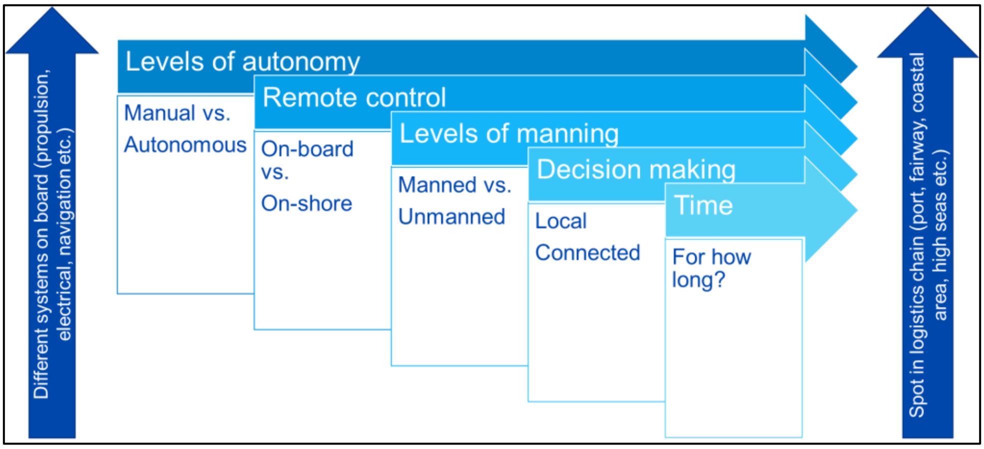


Figure 6: Dimensions of autonomy levels to be considered (One Sea)

There was a proposal by Australia at IMO 100 Maritime Safety Committee (MSC100) meeting, regarding general levels of autonomy[76] that was postponed to later MSC meetings due to the current workload on the scoping exercise. In the document technical **levels of automation** (4) are separated from **levels of operational control** (2) (see figure 7). CCNR has agreed on definitions of autonomy to Inland Waterway Transport (IWT)[77] with five levels of autonomy. Those levels of autonomy can be seen below in figure 8.

| **Level of automation** | **Explanation** |
|---|---|
| A0 - Manual | Manual operation and control of ship systems and functions, including basic individual system level automation for simple tasks and functions. |
| A1 - Delegated | Permission is required for the execution of functions, decisions and actions; the operator can override the system at any stage. |
| A2 - Supervised | The qualified operator is always informed of all decisions taken by the system. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the system at any stage. |
| A3 - Autonomous | The qualified operator is informed by the system in case of emergency or when ship systems are outside of defined parameters. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the ship system when outside of defined parameters. Provided the boundaries of the ship system are not exceeded, "human control" becomes "human supervision". |
| | |
| **Level of operational control** | **Explanation** |
| B1 - Qualified operators | (deck and/or engine) are on board the ship to exercise meaningful human control, within the design intent of the system. |
| B0 - No qualified operators | (deck and/or engine) are on board but exercise of meaningful human control/supervision is available remotely |

Figure 7: Proposal at IMO MSC 100 for levels of automation

76 IMO MSC 100/5/6

77 CCNR Proposed definition of levels of automation in inland navigation (Revision 1)

| | Level | Designation | Vessel command (steering, propulsion, wheelhouse, ...) | Monitoring of and responding to navigational environment | Fallback performance of dynamic navigation tasks | Remote control |
|---|---|---|---|---|---|---|
| BOATMASTER PERFORMS PART OR ALL OF THE DYNAMIC NAVIGATION TASKS | 0 | **NO AUTOMATION**<br>the full-time performance by the human boatmaster of all aspects of the dynamic navigation tasks, even when supported by warning or intervention systems<br>*E.g. navigation with support of radar installation* | | | | No |
| | 1 | **STEERING ASSISTANCE**<br>the context-specific performance by a steering automation system using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks<br>*E.g. rate-of-turn regulator*<br>*E.g. trackpilot (track-keeping system for inland vessels along pre-defined guiding lines)* | | | | |
| | 2 | **PARTIAL AUTOMATION**<br>the context-specific performance by a navigation automation system of both steering and propulsion using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks | | | | Subject to context specific execution, remote control is possible (vessel command, monitoring of and responding to navigational environment and fallback performance). It may have an influence on crew requirements (number or qualification). |
| SYSTEM PERFORMS THE ENTIRE DYNAMIC NAVIGATION TASKS (WHEN ENGAGED) | 3 | **CONDITIONAL AUTOMATION**<br>the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks, including collision avoidance, with the expectation that the human boatmaster will be receptive to requests to intervene and to system failures and will respond appropriately | | | | |
| | 4 | **HIGH AUTOMATION**<br>the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks and fallback performance, without expecting a human boatmaster responding to a request to intervene[1]<br>*E.g. vessel operating on a canal section between two successive locks (environment well known), but the automation system is not able to manage alone the passage through the lock (requiring human intervention)* | | | | |
| | 5 | **AUTONOMOUS = FULL AUTOMATION**<br>the sustained and unconditional performance by a navigation automation system of all dynamic navigation tasks and fallback performance, without expecting a human boatmaster responding to a request to intervene | | | | |

[1] This level introduces two different functionalities: the ability of "normal" operation without expecting human intervention and the exhaustive fallback performance. Two sub-levels could be envisaged.

Figure 8: CCNR levels of automation

## *2.2 Holistic Description of the State of the Art*

Background

The development of automated and connected maritime and inland waterway transport has been led by actors within the Baltic Sea and Benelux region where for example integrated sea traffic management systems have been developed and deployed and electronic River Information Services are in operation. With the exception of military applications, autonomous waterborne traffic remains at the development stage with increasingly advanced and large-scale testing. Testing has been undertaken within national waters and on waterways where the national authority can specify the conditions rules for operation and if necessary, amend national law.

The Norwegian "Yara Birkland"[78], is expected to be the first fully autonomous commercial shipping service and will use a battery electric ship to transfer shipping containers from the Yara fertiliser factory 20 nautical miles around the Norwegian coast to the nearby port removing around 20,000 lorry journeys

[78] www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/4B8113B707A50A4FC125811D00407045?OpenDocument

from the local roads each year. The vessel is under construction and is expected to enter service in 2020 and achieve fully autonomy around 2022.

The Sea Traffic Management – Validation project[79] supported by the European Connecting Europe Facility and Interreg, engages many European countries and its preliminary reports addressing large pan-European testbeds are showing potentially important improvements towards increased safety and sustainability. Large scale traffic Management is achieved through increased connectivity, integration with navigational systems together with seamless data transfer towards all of the relevant actors. The Sea Traffic Management project has potential to become a significant contributor to achieving the UN climate goals, take VTS (Vessel management Traffic System) to the next level and to vastly improve vessel monitoring, which will provide an essential prerequisite towards increased levels of CAT.

Among the first waterborne automated systems to be introduced to the market are situational awareness systems with sensor fusion, automated docking systems and auto-crossing systems for short stretches[80]. Situational awareness products observe the vessel's surroundings in ways beyond the capabilities of the human eye, using sensor technologies. Automated harbour operations and piloting are also being tested and are available commercially[81]. Presently Europe has a good competitive position for this type of product and has released most of the developments towards the wider market. However, there is rapidly growing know-how regarding autonomous waterborne operations elsewhere including the USA and China, where the focus is mostly military side[82].

The largest global shipping companies are developing increasingly advanced and integrated cargo management, logistics and certification systems and are undertaking initial trails utilising block chain technologies. The vulnerability and risks of such systems was illustrated in May 2017 with a wide spread ransomware attack which caused one of the world's largest shippers to revert to paper operations and impacted global trade. Apart from the interrupted business, the recovery costs were reportedly 100's of millions of USD.

IMO's Maritime Safety Committee discussed automated ships as early as 1964[83]. Autopilot has been used on ships for almost 100 years[84]. Condition-based monitoring systems have been offered to different ship systems at least since 1990s. But it was not until the early part of 2010 that the waterborne industries really started taking automated waterborne traffic seriously. The solutions that are being built are mainly not built on current autopilots, but rather by utilizing Dynamic Positioning (DP) technologies, that have also been

[79] www.stmvalidation.eu/
[80] See e.g. http://www.abb.com/cawp/seitp202/cb99bdc1a0fe4de9c12581df002e46ca.aspx , www.rolls-royce.com/media/press-releases/2018/17-04-2018-rr-to-supply-innovative-autocrossing-system-and-propellers-to-13-new-ferries.aspx , www.wartsila.com/twentyfour7/innovation/look-ma-no-hands-auto-docking-ferry-successfully-tested-in-norway
[81] See e.g. www.youtube.com/watch?v=bn2GPNJmR7A
[82] See E.g. the Sea Hunter in US en.wikipedia.org/wiki/Sea_Hunter
[83] MSC VIII/11, 9.3.1964
[84] en.wikipedia.org/wiki/Self-steering_gear

in use in some areas of the waterborne field already for some time, with the first commercial DP system being released in 1977[85].

Now industries, researchers and authorities are seeking to move forward and maximise the benefits of CAT for shipping, ships, logistics, ports and waterways.

Globally there are now three high level technological drivers in the field of connected and automated waterborne technologies. The first one is technologies to improve safety and the second is digitalization to increase the efficiency of operations, interconnectivity between systems and business models. Thirdly the driver is to address environmental issues by for example enabling new business models, which can transfer road freight towards automated vessel. These themes encompassing safety, digitalisation and environment are interlinked and also relate to improved security, life cycle approaches, blue growth deployments, logistic integration and intermodality and efficiency in ports. The landscape for the human element will change dramatically as the industry change towards a higher degree of automatization. Therefore, the human factor can be seen as a fourth technological influencer. Whilst there have been some smaller start-ups, digital innovations seem to be more driven by the established Original Equipment Manufacturers (OEM) who also strive to integrate between their different on-board systems.

Automated traffic related solutions (or smart/intelligent systems, as the suppliers call them) have become one of the most talked about and most visible of the many digital solutions that are offered in the market. Several existing OEMs have started creating a product palette that in the future could contain all the parts for automated waterborne transport. The efforts were isolated to begin with, so that the companies focused on ships, aquatic military drones, harbour equipment and waterway infrastructure or some specific part of the waterborne logistics chain. But today there seems to be a common understanding that the business potential of these systems cannot be reached if they are applied in isolation. To gain full advantage, the entire logistics chain needs to embrace automated and connected technologies and these efforts need to be coordinated between land, sea or inland waterways, point of origin and final destination.

Concerning the construction of commercial cargo ships on the waterborne side, Europe has been losing ground to Far-Eastern countries, mainly China, South-Korea and Japan. On the shipbuilding side European shipyards have maintained their competitiveness regarding building of complex passenger vessels and highly specialised vessels. Electronics for waterborne applications is an area where Europe is strong and European OEMs have remained competitive and supply a large proportion of the equipment of the world's commercial vessels. Europeans are also the largest owners of global shipping, for example controlling or owning more than 40% of all container ships[86].

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[85] stories.kongsberg.com/content/story-behind-dynamic-positioning
[86] For statistics see e.g. here www.statista.com/topics/3712/shipbuilding-industry/

State of the art

In the last STRIA report[87] it was stated that: "Ship Autonomy is a new field with little technology available today. Some demonstrations have been made of suitable technology, e.g. in the MUNIN project, but this is still on a low technology readiness level. Automation systems, such as dynamic positioning, contain some elements of autonomy. Automated berthing has been demonstrated in some special cases." The situation has changed quite dramatically in the few years since[88].

It seems that on the waterborne side many of the technologies needed, have been ready (e.g. dynamic positioning systems, some condition-based maintenance etc.). Regarding the development of those technologies that the waterborne sector has so far not taken up widely (e.g. situational awareness etc.) experiences from other fields have been utilized. Development of more automated solutions requires a wide field of technologies to be incorporated into the products and that can be done either by cooperating with other fields of automated and connected traffic or ICT (Information and Communications Technology) or by investing heavily in obtaining the technologies. Both methods have been applied by the companies developing the technologies.

The developments in automated and connected technologies need to take into account the variety of vessel types, operational conditions etc. Therefore, there are different approaches to automated and connected technologies in the waterborne sector. Increased autonomy and remote control seem to be offered by many companies. It is offered also to vessel types, where the crewing costs are a small part of the vessels operational cost. In these cases, technologies are used to increase safety, improve the working conditions of the crew or optimize logistics and energy efficiency. The expected decrease in fuel consumption is a powerful financial inducement. Remote controlled technologies have been both tested and applied. One of the trends seems to be to move decision making from on board to shore. These new technologies are developed to all systems on board, from navigation to propulsion and some coordination is therefore needed. The automated and connected systems are offered from cargo handling in ports through inland waterways infrastructure to vessel operation.

Situational awareness, condition-based maintenance, decision support and traffic management systems such as for example STM, have reached the commercial stage or are coming there rapidly. However, steps can still be taken to increase the sophistication and capability of such systems and the automatic interpretation of the resulting data as a prerequisite for autonomous waterborne traffic. Sensor technologies, including sensor fusion and machine vision keep developing in many areas and are being applied to many of these applications. AI and cyber security are also constantly developing, offering new interesting solutions to the industry. Despite so many products entering the market, the

SWD (2017) 223 'Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package. Brussels, 31.5.2017 ec.europa.eu/programmes/horizon2020/en/news/connected-and-automated-transport-expert-group-report

[88] Global Marine Technology Trends 2030, Autonomous Systems, August 2017.

actors in waterborne sector have not implemented them widely yet. One of the reasons is that the products needed are still very expensive and especially connectivity at sea is expensive and sometimes even non-existing. On the other hand, fully autonomous systems require a lower degree of "on line connection" compared with the previously mentioned remote controlled ships. There is also a tradition within the waterborne sector with the market waiting to see the performance of these first commercial applications. Therefore, demonstrator projects are especially important. The industry, academia and many countries have created alliances to cope with the multitude of connected and automated technologies. For a list of the alliances, see chapter 6. Common terminology and regulations are also needed. The regulation work has been started both for inland waterway and maritime transport. European countries have been very active in this process together with some Asian countries and North America.

Summary of state of the art based on the action sheets

Regarding **in-vessel enablers**, on-board technologies enabling the autonomy of vessels and their various systems have already for some time been studied, developed, implemented and tested. Various automated technologies exist for different functions of the different types of vessels. However, an overall approach on how the technologies interact, with both humans and other systems, must be developed and tested. Validation and assurance closely linked to the development of IT architecture and certification is needed as well as integration of various data layers and the adaption of rules and regulations.

For **condition and operational monitoring services**, there are services available for individual waterborne installations, but now there needs to be a next step towards more proactive failure prediction and the merging of data across systems. Existing data, such as information on carried cargo, must be transferred through the logistics chain and between transport modes better, and ways to collect the necessary data, that is not there yet, in a cost-efficient way, must be developed. Operational compliance monitoring is mainly undertaken through port inspection and the examination of record books but could also be more extensive and digitised to increase assurance.

State of the art regarding **validation and demonstration** is that currently there are automated waterborne cargo and passenger services[89], but they need to be integrated and implemented in regular operations, to create the automated vessels and transport systems. Experimental remote operating centres have been established. There are various systems of autodocking and automated cargo/passenger handling systems for harbours. There also exists various networks that can be utilized for automated or remote-controlled operations. However, there are no existing complete infrastructures that are planned for automated or remote-controlled systems. Autodocking systems exist but are not integrated to automated logistics, such as loading, unloading. Robotised shore side container terminals exist although ship loading and

[89] E.g. www.newscientist.com/article/2167440-robot-port-in-china-to-unload-shipping-containers-without-humans/ , www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx and new.abb.com/news/detail/11632/abb-enables-groundbreaking-trial-of-remotely-operated-passenger-ferry

unloading is under human control. Testing and operation are mainly done within areas of restricted traffic. Testing of autonomous operation using on board sensors and on-board decision in simulated normal traffic conditions has been undertaken in Finland in the fall of 2018[90]. For inland waterway transport, lock and bridge remote control systems are tested and deployed. Technologies developed for automated and remote-controlled waterborne traffic could also be used for remote piloting. The fairways also have to be developed and adapted to support automated and connected shipping and Inland Waterway Transport (IWT).

Military autonomous and remote-control vehicles are operational. Many of the technologies for automated vessels, such as situational awareness, decision support, dynamic positioning and condition monitoring are commercially available[91]. One of the things that is still missing is a demonstrator where these technologies would all be used together to create the automated ship and the commercial feasibility and safety of the entire concept would be proven.

For **electronic information exchange and certification**, the current international regulatory framework is only to certain extent appropriate for automated waterborne vehicles. A regulatory scoping exercise has been started at the IMO level. Regulatory activities launched at the level of Rhine and/or Danube Commissions have so far been started. Converting data into information and sharing it for process/product optimisation need data models and interoperability standards. Development of digital twin for highly complex products as a ship to be used along her whole operational life (more 20-30 years) also needs standards. Business to Administration (B2A) electronic reporting and Business to Business (B2B) electronic reporting needs a common electronic language. There also needs to be focus on data quality as well as standardization of data collection.

Ships are becoming more and more automated ("smart ships"). At the same time, EU, IMO, CCNR etc. regulatory long-term path aims at electronic compliance (beyond the e.g. electronic reporting formalities already in place in the EU). Better ship operations management, monitoring and control will (is already) positively impacting safety, reduction of administrative burden, logistic chain efficiency and ultimately energy efficiency. Cheap broad band coverage world-wide will enable full ship connectivity. Already today ships operating in highly connected areas (e.g. cruise and ferries) are monitored from shore centres which provide routing and operational suggestions for e.g. energy efficiency, traffic avoidance and just in time arrival purposes. In this context, systems supporting sea traffic management have been developed, tested and validated. Large onboard systems (e.g. main engines) are shore monitored in view of maintenance optimization. Internet of Things based sensors and components are gradually being installed on board.

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[90] www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx

[91] E.g. http://www.abb.com/cawp/seitp202/cb99bdc1a0fe4de9c12581df002e46ca.aspx , www.wartsila.com/services/areas-of-expertise/services-catalogue/propulsion-services/propulsion-condition-monitoring-service and www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/14E17775E088ADC2C1256A4700319B04?OpenDocument

For **Socio-Economic impact** of CAT, there is no awareness of developments in other transport modes (mainly roads) in waterborne and there is lack of presence of waterborne in existing analyses. Regarding assessment of risk and public and stakeholder acceptance there are running discussions in other modes of transport. The discussion should be about how automation and autonomy can increase sustainability, efficiency and reduce emissions. Furthermore, the models for calculating and analysing the socio-economic effects of automated and connected transport have to be further developed and updated.

Regarding **changed working conditions** it is obvious that the automation is increasing. There will be need for additional skills from seafarers as well as a need to adapt to changed social working conditions, both on-board and ashore. Machines can help humans to perform better or faster, however, with increased automation the way we communicate with machines needs to be developed, tested and standardized. Earlier research on work in distributed teams (e.g. disaster rescue teams) shows that authority and decision-making challenges arise due to ambiguity on who should be in charge, lack of trust/lack of information, and situation awareness challenges.

State of the art for **physical and digital infrastructure** is that there are satellite and GSM based data services for AIS,[92] condition monitoring and general communication. AIS and RIS are used as identification systems. Today satellite data is comparatively slow or expensive. 4G systems have insufficient coverage and bandwidth, 5G is being rolled out in some areas and with its increased down-load speed, low latency and built-in priority key elements for a maritime (close to land) network is available. However, as the range of 5G is smaller than 4G, the solutions are rather local. The capacity of data transfer might not be enough if the needs to transfer data increase dramatically. River Information Services are available within national jurisdictions, but the data is not shared across borders. The lack of sophisticated scheduling of ships in ports leads to the fact that ships inefficiently rush to port and then stand by offshore waiting for a mooring or come the last part of the journey extremely slow. For port CDM[93] (part of the STM validation projects), contracted arrival time is not always compatible with port capacity. This is today largely manual and could be more done in a more efficient and automated way. Feeding from ports IWT is impacted by this. E-charts are deployed. The physical infrastructure in fairways, harbour basins and inland waterways also has to be adapted to automated and connected waterborne traffic.

State of the art for **situational awareness** is that intelligent machine vision is quite advanced. On the waterborne side there are several products e.g. ABB Ability Marine Pilot Vision and Rolls-Royce Intelligent Awareness. However, automatically interpreting and acting upon machine vision in very complex and busy environments remains under development and testing. Ship applications normally have more sensors of different type than cars, thus enabling a better overall picture of the situation, yet there is a need to cope with varying conditions, e.g. low hazard frequency but unstable platform (ship movements) during a deep-sea storm vs complex multi hazard environment and

[92] Eg. www.businesswire.com/news/home/20030403005674/en/Nokia-Delivers-Total-GPRS-Solution-AIS
[93] http://stmvalidation.eu/news/portcdm-information-sharing-in-real-time/

comparatively stable platform when approaching port. There is need to identify vessel types and their capability, and distinguish other features, such as floating hazards, rocks, waves etc. and combine that with other data (wind, wave current, heading) to ensure safe passage, or to alert for human intervention. There are currently class certified available products able to do this. On-board and off-shore sensor and other data are fused and intelligently interpreted from many sources e.g. camera, LIDAR, radar, AIS, depth, wind, wave, wind, rudder, speed, intercepting paths. There are still some challenges with the utilisation of certain sensor technology at sea (e.g. LiDAR) and sensor fusion is continually under development. Current decision support systems, developed to utilize the situational awareness, are built on DP (Dynamic positioning) rather than autopilot.

Regarding **big data** remote operational monitoring centres gather data to improve the efficiency and safety of global fleets. Global AIS data is publicly available, though its accuracy is not enough for future connected and automated uses. There is research to improve this through DGNSS information. However, AIS data can be aggregated to provide potentially important information concerning for example fuel consumption, safe ship movements and near misses. Global weather, wave and increasingly satellite data and imaging are available. Continuous condition monitoring of fuel consumption system status etc. is applied in many companies, there is a move towards evidence based efficient operations.

**Technologies to ensure safety and security of communication exchanges** are commonly available and deployed, e.g. in military and European aeronautical applications. Therefore, existing solutions could partially be used to develop new technologies. There are also existing products that have been specifically developed for the waterborne industry. How to apply the existing technologies to good solutions is being researched.

# 3 Hurdles and Opportunities

*This chapter summarises the most relevant barriers for and chances of the implementation of connected and automated waterborne transport in Europe. Like the description of the state of the art in the previous chapter, technical and non-technical dimensions are referred to by technology, legal, societal, economic, and human factors layers, and assessments by the involved stakeholders are closely considered. Also, interdependencies are identified. This shall serve as basis for building the plan of initiatives and actions in the following chapters.*

Dimensions to be considered

A **technological** issue for waterborne transport that is less of an issue for land-based industry is that the availability of connectivity, related infrastructure and authentication can be limited. Several technologies can address these issues. The most straightforward, but presently costly solution, is to increase satellite coverage and bandwidth. The current microsatellite efforts could help and are well on their way. 5G technology is also emerging and the first 5G pilots have been launched in Europe and will be beneficial for inland waterway and some coastal services[94]. There is also a lot of research into lessening the need to transfer data or the amount of data to transfer. A third solution is to go for fully autonomous rather than remote controlled solutions, as those need less data transfer. Alternative communication possibilities at far sea should also be investigated. In order to benefit all waterborne segments, cost of the technological solutions must also be considered.

Another important technological challenge is cyber security. Risks of various cyber attacks increase, as the waterborne traffic becomes more automated and connected. Traditionally vessels have been protected, at least in part, by the lack of connectivity. As the operations become more connected, cyber security needs to be addressed both on a systemic and individual level (e.g. recent reports of corruption of GPS navigation signal for ships).

Remote controlled or automated systems can also **enhance safety** and provide more ergonomic working places as well as better working hours and possibility for the crew to spend more time at home. Additionally, it is expected, that the work performed by the **human** can be made more interesting and specialized when the same task is performed on a fleet compared to only one vessel. With a change of task to be performed by the human, it is possible to see patterns and benefits not seen when only working with one vessel. There is a clear societal benefit in general there, as well as on a personal level, for the people working with waterborne transport ashore. As the number of autonomous vessels increase the need for workers in shore control centres will also increase resulting in a shift towards “office” work and better working conditions as described above.

[94] E.g. www.teliacompany.com/en/news/news-articles/2018/5g-helsinki/ and www.telenor.com/media/press-release/telenor-group-launches-the-first-5g-pilot-in-scandinavia

With the new technologies, the education and training of the current workers in the waterborne sector will require changes. Connected and automated transport will have a huge impact on existing education and training modules. The knowledge, skills and competences required of the employees will change, be it on-board or in the equipment or shipbuilding industry. Increasing automation when humans are still in the loop, also causes its own problems, with lack of situational awareness and high probability that humans take wrong corrective measures when stressed. A more holistic view of the full risk picture is needed.

There is also an **environmental** aspect to the intelligent systems on board. Artificial intelligence can plan routes and steer vessels and machines more efficiently than humans thus saving fuel and reducing emissions. Merely for ships, the effect of a few percentages fuel saved, is staggering on a global scale. Vessels using automated technologies also more easily implemented through electric power solutions, such as batteries instead of diesel. Human error remains the principal cause of maritime accidents and the consequent reduction of the human element is expected to limit accidents and minimize polluting emissions into the sea and all kinds of waterways.

The **economic benefits** come mainly from improving the efficiency of logistics chains. Better utilizing and combining available data and AI can make many functions in the logistics chain more efficient and enable the more effective utilisation of existing vessel capacity. Also, smaller ships can provide new logistics solutions with differentiated speed to different customer groups and more frequent departures to all. Smaller ships will in general have an increased cost with increased number of crew, which is one possible application of partial or full autonomy. On a global level use of these technologies, may make European actors more competitive. However, investing in the first applications comes with a higher investment cost and this has led to difficulties on the part of traditional ship owners and operators, who are facing difficult markets with over capacity within the sector driving down cargo rates. End users of the cargo (manufacturers, citizens etc.) have been more interested in these new technologies and may in the future disrupt the waterborne transport and logistics chains.

For the traditional large suppliers of waterborne equipment and European shipbuilders, the growing CAT technology developments provide a pathway towards an increasingly digitalized and (hopefully) carbon free future. The suppliers often have extensive knowledge of several ship systems and have developed digital solutions for their own products, that can easily be converted to serve the needs of connected and automated solutions. Some European manufacturers have jumped at the chance to develop these technologies and are now well ahead of the competition.

<u>The automated and connected landscape from a waterborne transport perspective</u>

Regarding research, as well as advancing technology capabilities, there is a need to address the societal, ethical and human factor issues. Although the products are currently being developed, there is uncertainty within the market where demonstrators can help to provide confidence in the capability, readiness and utility of the technologies. The companies will also need investment funding, as this is a new business area for many, requiring a lot of investments. The major bottlenecks are the legislative issues and the connectivity at sea, which both will need investments and research.

In the previous STRIA report[95] social acceptability, regulatory frameworks and financial frameworks were mentioned as implementation barriers. Social acceptability is still an issue, but maybe less for waterborne compared to road transport. Regulatory frameworks are still needed, and international regulations will typically be developed over a long period. Financial frameworks are needed for the initial investment and validation. It seems as the technical challenges are the easiest to overcome with support from research.

In the Global Marine technology trends 2030 report[96] some key challenges for the future are mentioned. The business environment in the waterborne industry is often considered conservative. Below are the challenges mentioned in the report with some comments, based on the discussions at STRIA CAT Waterborne workshops[97].

How the technology is developed, validated and applied in an automated system? In the workshop sessions the issue of validation came up frequently.

Challenges associated with technology insertion and integration with existing assets. Integration was one of the most important issues.

Associated risks dependability/reliability in operation and overall system safety justification. This is somewhat harder to deal with in connection with R&I actions, but e.g. the standardization efforts in the action sheets try to tackle this issue.

Affordability and whether the technology represent a compelling infrastructure investment case. The demonstrator case was needed precisely for this reason.

Business, regulatory and legal environment were also mentioned in the report as they were in the last STRIA report. The socio-technical challenges and societal acceptance were also taken up. The DNV GL report on remote-controlled and autonomous ships[98] takes up the exact same issues.

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[95] Connected and Automated Transport. Studies and Reports. European Commission 2017
[96] Global Marine Technology Trends 2030, Autonomous Systems, August 2017.
[97] See page 6.
[98] DNV GL: Group technology & research position paper 2018 Remote-controlled and Autonomous Ships in the Marine Industry

# 4 Roadmaps and Plans

*Not many roadmaps for the development of connected and automated waterborne traffic have been produced. In this chapter, the roadmap approaches of AAWA (a research program) and One Sea, an industry-based ecosystem and UK Marine Industries Alliance are summarized. Their findings have been considered in the drafting of the action sheets for the plan at hand.*

## *4.1 Various roadmaps on the waterborne side*

The previous STRIA report[99] refers to national roadmaps in Norway[100] and the Netherlands[101] as well as companies such as DNV GL[102] and Lloyds Register[103]. However, it must be taken into account the connected and automated waterborne transport has significantly developed since these publications and these further developments must be taken into account.

Some of the earlier roadmaps expected development from local to international and through remote control towards fully autonomous vessels. The part about local solutions seems to be true still, but the medium stage of remote-controlled vessels is not so clear anymore. There also seems to be interest towards vessels that can be both autonomous and remote controlled, depending on the situation. The Yara Birkland, is the first autonomous ship on order to become fully autonomous in stages following initial trials with crew and then a period under remote control. The Yara Birkeland that will have a "removable" bridge in the first phase that will be utilised to support full testing of autonomous functionality in a commercial environment[104].

There can be several reasons to this trend of going towards fully autonomous straight away. Ships are investment objects with a long lifetime. It is not feasible to acquire a vessel with technologies developed for the transition stage, as they might not be competitive during the final years of their life-time. Remote controlling a ship also requires a lot of band-width for information exchange. Fully autonomous vessels manage with less. There is also a need to develop fully autonomous fail-safe solutions to the remote-controlled vessels in case the connection is severed.

The AAWA whitepaper[105] introduced pretty much that view, but in somewhat more complicated format. The AAWA roadmap (see figure 9) also addresses the important issues of societal acceptance and adaptation. The roadmap has not been put on a timeline, but the basic idea of going through remote control phase is in this roadmap too. The fact that situational awareness systems have

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[99] Connected and Automated Transport. Studies and Reports. European Commission 2017
[100] See http://www.maritim21.no/prognett-Maritim21/Forside/1254006265186 (In Norwegian)
[101] The Dutch Maritime Strategy 2015 – 2025, January 2015. Available from www.noordzeeloket.nl/images/The%20Dutch%20Maritime%20Strategy%202015-2025_4995.pdf
[102] See www.dnvgl.com/technology-innovation/sri/index.html
[103] See http://www.lr.org/en/research-and-innovation/
[104] www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/4B8113B707A50A4FC125811D00407045?OpenDocument
[105] Remote and Autonomous Ships The next steps, AAWA position paper © Rolls-Royce plc, 83

led to decision support systems in real life, adds to the credibility of this roadmap. The roadmap also introduces some inputs that were taken up in the STRIA action sheets.

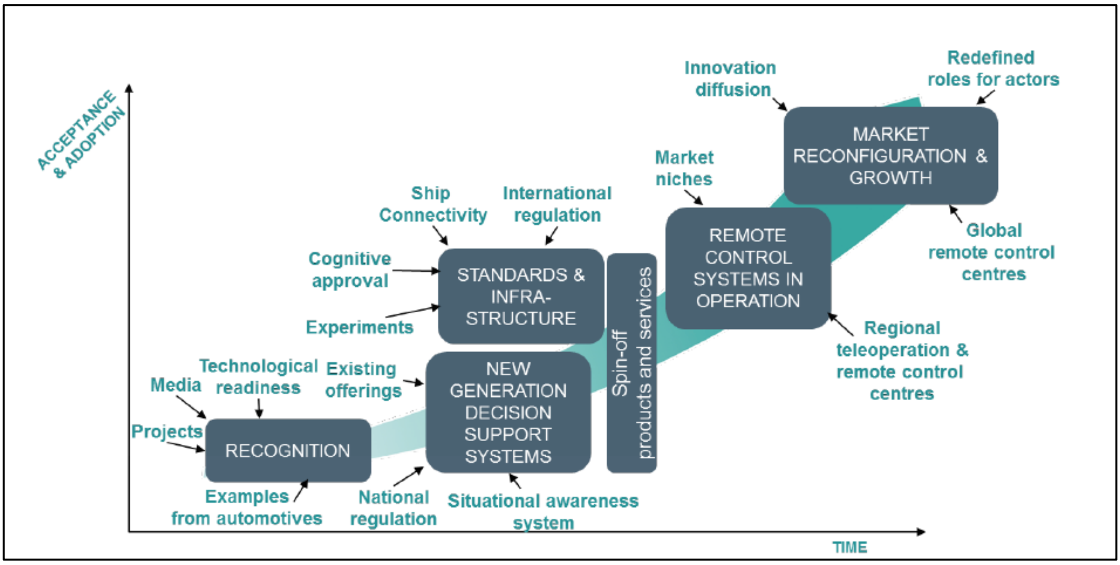


Figure 9: Transition roadmap for autonomous shipping (AAWA)

The One Sea – Autonomous Maritime Ecosystem, has published their roadmaps for the autonomy development during the first half of 2017[106].

As can be seen in figure 10, the expectation seems to be that the autonomy will move from remote monitoring through remote control to fully autonomous vessels. The plan was to use national and global pilots to verify the technologies and to gain acceptance to their use.

UK Marine industries completed a technology roadmap in 2015[107]. This roadmap is a few years older than the One Sea roadmap. It also looks more widely at maritime trends. Autonomous technologies and vessels are considered an important opportunity for the industry. The roadmap places the vessels in medium to long term range time-wise, 2019-2030. This roadmap is relevant still today, when considering development of connected and automated transport.

[106] One Sea – Autonomous Maritime Ecosystem has published their roadmaps on their website www.oneseaecosystem.net/roadmap/
[107] UK Marine Industries: Technology Roadmap 2015

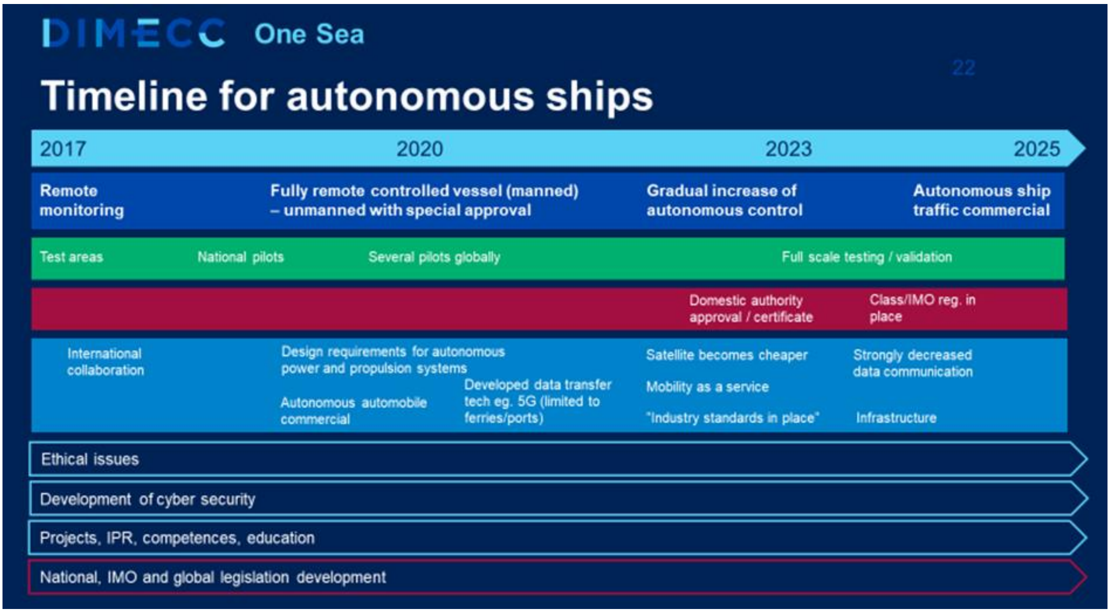


Figure 10. Timeline for autonomous maritime traffic (One Sea)

In reality, for some vessel types and services, the schedule has been even faster than the roadmaps indicate. Several global tests of remote-controlled vessels have been conducted and pilots are now operational[108]. Many companies have introduced autonomy-related products[109]. The first vessel (Yara Birkeland), with its accompanying logistical systems has been contracted and it is to be launched early 2020 and is planned to gradually move from manned operation, though a period of remote control to a dedicated fully autonomous coastal shipping service by 2022[110].

## *4.2 Plans for connected and automated waterborne traffic*

According to the information provided by the stakeholders, many initiatives are planned currently in the field connected and automated waterborne traffic.

- Rotterdam harbour and the Danish and Finnish piloting companies are experimenting and planning remote piloting.

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[108] E.g. Rolls-Royce and Svitzer demonstrated the world's first remotely operated commercial vessel in Copenhagen harbour, Denmark www.rolls-royce.com/media/press-releases/2017/20-06-2017-rr-demonstrates-worlds-first-remotely-operated-commercial-vessel.aspx and Wärtsilä tested remote operating of an Offshore supply vessel in the North Sea from San Diego California www.wartsila.com/media/news/01-09-2017-wartsila-successfully-tests-remote-control-ship-operating-capability

[109] E.g. ABB Marine Pilot Vision http://www.abb.com/cawp/seitp202/cb99bdc1a0fe4de9c12581df002e46ca.aspx and Kongsberg bridge www.km.kongsberg.com/ks/web/nokbg0237.nsf/AllWeb/DCDA899160E86A0AC12582F9002D9D55?OpenDocument Sea Machines SM400 sea-machines.com/products

[110] www.yara.com/corporate-releases/yara-selects-norwegian-shipbuilder-vard-for-zero-emission-vessel-yara-birkeland/

- The Flemish Region of Belgium adopted its own roadmap for smart shipping, which includes autonomous vessels. Since May 2018 the whole network of waterway manager De Vlaamse Waterweg is designated as test area for autonomous vessels[111].

- The German government has decided to develop a Masterplan that is dealing with "Digitalization of Inland Waterways". The focus here is on transport and logistics, but the subject of automatic navigation and autonomous shipping is also discussed.

- The German Maritime Research Strategy 2025 offers two funding initiatives including the "Maritime Research Programme" that supports the national research community as well as the industry for ship-building and marine technologies. Digitalisation and smart technologies including industry 4.0 standards in the production processes as well as the use of intelligent sensor technologies, network technologies, big data, robotic systems, higher automation, autonomy technologies and the use of smart materials are subject of a new funding priority, referred to as "MARITIME smart".

- The Norwegian government[112] and industry[113] are probably going to update their strategies for maritime opportunities.

- UK maritime strategy: Maritime 2050, is due for publication in early 2019.

- French Maritime Cluster (CMF) is finalising a Guide to Good Practice on Maritime Drones for Unmanned Surface Vehicle (USV) and Unmanned Underwater Vehicle (UUV).

- The Finnish government is initiating a traffic and growth program and a cyber security growth program.

- The Netherlands government together with industry, research and education institutes is planning to create a roadmap including a knowledge agenda in 2019.

- The Spanish Ministry of industry, Trade and Tourism has recently issued an Agenda for the Naval industry (2019) where 10 challenges are identified and the following are related to the development of autonomous ships: digitalization, research and development activities and sustainable transport. The Spanish Ministry of Public Works and Transport has launched a Transport & Infrastructure Innovation Plan (2017) that develops the innovation strategy covering e-maritime.

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[111] www.vlaamsewaterweg.be/smart-shipping-english-version
[112] www.regjeringen.no/en/dokumenter/maritime-opportunities--blue-growth-for-a-green-future/id2413857/
[113] maritim21.no/prognett-Maritim21/Nyheter/Mange_muligheter_for_Norge_som_maritim_nasjon/1254021981874/p1254006265230

- Blue Line Logistics is developing a concept about autonomous cargo ships in Northern Europe.

EU plans:

- European ports are planning a new Sea Traffic Management (STM) project[114].
- A number of STM related projects are in start-up phase and in application phase.
- There is consultation ongoing in EU about an electronic tool for Inland Waterways Transport[115].
- 3rd EU transport package (17.5.2018) and related initiatives on digitalisation of transport documents and proposal for a Regulation on a European Maritime Single Window environment are being developed.
- EU regional strategies for sea areas and inland waterways are also considering utilisation and development of connected and automated technologies.

Asian countries such as Korea, Japan, China and Singapore are all approaching the issue of connected and automated waterborne traffic in some way.

- The countries have all their respective alliances for autonomous traffic.
- The Chinese alliance[116] is working on a concrete cargo vessel that is to be autonomous and remote controlled. The alliance consists of companies that can supply technologies to the solution.
- Korean alliance is more research-based and is still being formed.
- In Japan there are 2 alliances that are created around 2 different ship owners[117]. The alliances are still forming, but some tests have been conducted.
- In Singapore the bigger focus has been on harbours[118].

Most of the non-European initiatives seem more research oriented and are generally less driven by good business cases. Thus, the general impression is that Europe at the moment has a solid lead in the area of CAT, but it is important to maintain this lead.

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[114] http://stmvalidation.eu/projects/monalisa-2/
[115] ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-6171228_en
[116] safety4sea.com/china-launches-unmanned-cargo-ship-development-alliance/
[117] www.theguardian.com/world/2017/jun/08/japanese-self-driving-cargo-ships-within-decade
[118] worldmaritimenews.com/archives/251143/singapore-to-develop-autonomous-vessels/

# 5 Programs and Projects

*The purpose of this chapter is to draw the landscape of the European Union's and Member States' previous and current actions in terms of programs and projects for innovation in connected and automated waterborne traffic.*

## *5.1 European Commission's programs and projects*

Already finalized EU research projects, that have been important to connected and automated waterborne transport, include:

- The MUNIN project (Maritime Unmanned Navigation through Intelligence in Networks) was a collaborative research project, co-funded by the European Commissions under its Seventh Framework Programme. MUNIN aimed to develop and verify a concept for an autonomous ship[119].

- EfficienSea2 was also co-funded by the European Commissions under its Seventh Framework Programme and has created and implemented innovative and smart solutions for efficient, safe and sustainable traffic at sea through improved connectivity for ships[120].

- The MONALISA project lasted 2010-2013 and demonstrated route planning and route sharing, which is the forebearer of Sea Traffic Management Validation Project – STM[121].

- Navigational Decision Support System for Improved COLREGs Safety Management was a NAVDEC project[122].

Ongoing EU projects related to connected and automated waterborne traffic include:

- NOVIMAR, is an EU H2020 project. It aims for a platooning concept for transport by water, i.e. vessel train transport concept consisting of one crewed leader vessel followed by several lowly manned or unmanned follower vessels from different class.

- EGNSS Hull-to-Hull is an EU H2020 project that addresses the need of the maritime community to safely navigate near of other vessels and objects. This will be a fundamental requirement for autonomous vessels[123].

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[119] http://www.unmanned-ship.org/munin/
[120] efficiensea2.org/
[121] http://stmvalidation.eu/projects/monalisa/
[122] cordis.europa.eu/project/rcn/197417_en.html
[123] cordis.europa.eu/project/rcn/212899_en.html

- SEAHUB is an EU H2020 project that aims to build a Real-time Fleet Performance Centre (FPC) to optimize energy efficiency in Maritime Transport to reduce fuel consumption and harmful emissions[124].

- VDRConnect is an EU H2020 project that aims at a VDR-based vessel telematics solution[125].

- SELIS is an EU H2020 project that is aimed at delivering a 'platform for pan-European logistics applications'[126].

- AEOLIX is an EU H2020 project that is creating a data sharing network for logistics[127].

- Surveillance of MARiTime surroundings through lasER technology is an EU H2020 project[128].

- ST4W Interreg project at EU for inland waterways[129].

- European Maritime Single Window environment initiative is also being developed[130].

- Outcome from Horizon 2020 "The Autonomous ship" R&I and demonstration to be launched in 2019[131].

- Outcome from Horizon 2020 "Unmanned and autonomous survey activities at sea" R&I action to be launched in 2019[132].

- CEF Transport[133] deals with digitalisation of Short Sea Shipping and Administration info-structure (future EU Maritime Single Window and Port Community Systems, VTMS Directive, eFTI proposal by the EC, DINA).

- River Information Services (RIS): the CEF RIS COMEX project works on RIS corridor management overcoming the current national data barriers and covering 3 corridor service levels 1) enabling route planning by providing reliable fairway and infrastructure information; 2) enabling voyage planning and traffic management by providing reliable actual and predicted traffic information; 3) providing vessel specific information.

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124 cordis.europa.eu/project/rcn/207137_en.html
125 cordis.europa.eu/project/rcn/204393_en.html
126 http://www.selisproject.eu/About
127 http://aeolix.eu/media-clippings/
128 cordis.europa.eu/project/rcn/204981_en.html
129 http://www.nweurope.eu/projects/project-search/st4w-smart-tracking-data-network-for-shipment-by-inland-waterway/
130 ec.europa.eu/transport/modes/maritime/digital-services/e-maritime_en
131 ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/mg-3-2-2018.html
132 ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/mg-bg-01-2018.html
133 ec.europa.eu/inea/en/connecting-europe-facility

- DANTE = Danube region programme Interreg project that focusses on improving administrative procedures and processes for Danube IWT[134].

- IWT: ongoing work on terminal management tools carried out at seaport level to reduce congestion for hinterland connection. Electronic tool for Inland Waterways Transport[135].

- EC project Blueprint for the Shipping Industry, the project will start from 1 January 2019 onwards, addressing the change of needed skills and the fact that we must get ready also in the case that automation mean full assistance to a very reduced number of people onboard, dealing with emergencies only[136].

- Project CyClaDes concerns the human element in the design and operational ship life-cycle[137].

- 5G-MoNArch project is an EU project to develop 5G infrastructure.

- The SafeSeaNet system main purpose is collecting and sharing DOG information between relevant authorities and cross border[138].

- The PortCDM project, aiming at making the call more efficient than today, by precise information and no delays.

- BONUS Baltimari project sets out to review the current state of the art in risk analysis and decision support, focusing on the Baltic Sea area[139].

## *5.2 Member State and industry programs and projects*

There are various industry and research alliances in Europe.

- One Sea – Autonomous Maritime Ecosystem is a high-profile ecosystem with a primary aim to lead the way towards an operating autonomous maritime ecosystem by 2025[140].

- The UK Maritime Autonomous Systems Regulatory Working Group (MASWRG) has developed a Code of Conduct and Code of Practice for Maritime Autonomous Surface Ships (MASS)[141].

- Norway has established 2 autonomous test areas: Trondheim's fjord and Horten.

[134] http://www.interreg-danube.eu/approved-projects/dante
[135] ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-6171228_en
[136] www.etf-europe.org/activity/skillsea/
[137] http://www.cyclades-project.eu/CyClaDes/index.xhtml
[138] http://www.emsa.europa.eu/ssn-main/items.html?cid=113&id=1326
[139] www.aalto.fi/department-of-mechanical-engineering/bonus-baltimari
[140] www.oneseaecosystem.net/
[141] www.maritimeuk.org/media-centre/publications/industry-code-conduct-maritime-autonomous-systems/ and www.maritimeuk.org/media-centre/publications/maritime-autonomous-surface-ships-uk-code-practice/

- Norwegian Forum for Autonomous Ships (NFAS)[142] is an interest group for persons or organizations established in Norway, that are interested in the subject of autonomous ships.

- The Finnish Research Alliance for Autonomous Systems (RAAS)[143], plans to be a one-stop shop research environment for autonomous solutions and services development.

- In Germany projects concerning digital test fields on waterways were started. A project group for the test field on the Spree-Oder-Waterway was established bringing together stakeholders from ports, consultants, associations, scientist, shippers, vessel operators and the waterway administration.

- The PIANC World Association for Waterborne Transport Infrastructure working group will focus on smart shipping at inland waterways and look at the developments from the perspective of infrastructure providers and traffic managers of inland waterways to stimulate and maximize the deployment of smart shipping[144].

- In The Netherlands almost all inland waterways and the 12-mile-zone are open to experiments. A permit form government is required.

- Floating Lab Rotterdam: vessel equipped for testing smart systems; can be used by all interested parties.

- The Flemish region of Belgium established in October 2018 the research platform FLOAT[145], ‘Flanders on the Automated shipping Track’. In FLOAT government, academia and port authorities join forces to develop and roll-out autonomous shipping.

- INAS (International Network for Autonomous Ships)[146] established by autonomy organizations, where countries can exchange best practices in an informal network.

There are also concrete industry/national projects, where the goal is to build and test automated waterborne solutions and infrastructure.

- The Yara Birkeland, will be the world’s first fully electric and autonomous container ship, with zero emissions, that was ordered from VARD shipyard in August 2018[147].

- Norway is also testing an autonomous mini-ferry[148] and an urban water shuttle[149] is also being developed.

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[142] http://nfas.autonomous-ship.org/index-en.html
[143] autonomous.fi/
[144] http://www.pianc.org/
[145] www.portofantwerp.com/nl/news/vlaanderen-wil-topregio-voor-autonome-vaartuigen-worden
[146] http://www.autonomous-ship.org/
[147] www.yara.com/corporate-releases/yara-selects-norwegian-shipbuilder-vard-for-zero-emission-vessel-yara-birkeland/

- In Denmark there are several tests: a remote-controlled tug boat in the Copenhagen area, remote controlled supply/workboat in the Funen area, small autonomous ferry project in Aalborg and an unmanned Surface Vessel for fishing purposes.

- Maersk and IBM have developed the TradeLens Blockchain Shipping Solution[150]. It is an open industry platform underpinned by blockchain technology that enables sharing of real-time, end-to-end supply chain information among cargo owners, transportation providers, etc.

- The VisuRIS portal and app on the Vlaamse Waterweg[151].

- Gouwenaar 3.0 is a development of a mostly autonomous ship[152].

- The Joint Industry Project Autonomous Shipping in the Netherlands inventorises, integrates and demonstrates the available technology required for the use of vessels which are sailing without interference of crew on board, by combining remote monitoring and controlling with various levels of autonomy. The demonstration on the North Sea is scheduled for March 2019.

- Flemish waterway manager, De Vlaamse Waterweg aims to test autonomous inland waterway operations[153].

- In Finland there is the Intelligent fairway experiment, where sea markers are supplied with sensors[154].

- Denmark is also testing remote piloting through: shore-based harbour pilotage using drone technology and shore-based pilotage of vessels in transit through Danish waters.

- Remote control centres managing multiple locks have been tested in Elbe 4.0[155].

- SMASH a public private exchange network for smart shipping on inland waters and sea in the Netherlands also offers services for smart IWT[156].

- Blue Growth-related open data and information sharing on-going developments (e.g. Columbus project and/or EMODNET initiative).

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[148] www.maritime-executive.com/article/autonomous-mini-ferry-moves-forward-in-trondheim
[149] maritimecleantech.no/wp-content/uploads/2014/12/UWS-folder.pdf
[150] www.tradelens.com/
[151] www.visuris.be/
[152] www.nedcargo.com/2017/04/04/nedcargo-zet-in-op-semi-autonoom-varen-binnenvaart/
[153] www.vlaamsewaterweg.be/
[154] www.lvm.fi/en/-/testing-of-intelligent-fairways-scheduled-to-begin-next-year
[155] www.tentdays.eu/2018/assets/doc/25_04_URSKAS/25_04_URSKA_4/14h00_15h45/Jan%20Ninneman.pdf
[156] smashnederland.nl/

- IWT: ongoing work on terminal management tools carried out at seaport level to reduce congestion for hinterland connection. E.g. Port of Antwerp: nautical coordination, container handling via Barge Traffic System (BTS), consolidation of inland shipping volumes.

- VLIZ (Vlaams Instituut voor de Zee – Flemish Institute for the Sea) will take an unmanned surface vehicle into operation during 2019/2020. This vessel is for research purposes, not for cargo transport.

- Individual companies own developments and existing services such as e.g. Carnival's Neptune or ABB's shore centre.

- The Sisu project with Rolls-Royce and Svitzer in Denmark that demonstrated first in the world remote operation of a commercial vessel in 2017[157].

- The SVAN project by Rolls-Royce and Finferries in Finland that demonstrated first in the world fully autonomous navigation and remote operation of a passenger ferry in 2018[158].

Several national research programs or projects have also been initiated:

- FernSAMS[159] is a research initiative by Fraunhofer Institute, funded by the Federal Government of Germany, that aims for safer harbour manoeuvring through remote controlled tugs.

- There are several projects for autonomous underwater vehicles in Germany.

- AGaPaS was a former project for Autonomous Galileo-assisted passenger rescue at sea.

- The aim of the project SCIPPPER is the development of a driver assistance system for the automation of lock entry and exit in inland navigation in Germany.

- The German coordinated ERA-NET MarTERA also supports CAT projects. In the MarTERA project RoboVaaS, an innovative concept for retrievable robotic operations and services in offshore waters and port areas is being developed and tested in three applications.

- "Simulation and Demonstration of automated Navigation in IWT" National (German) Project proposal delivered to funding agency on Oct. 5th, 2018. After simulator-supported learning: test and demonstration of steering and control systems on a real vessel in real waterways.

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157 www.rolls-royce.com/media/press-releases/2017/20-06-2017-rr-demonstrates-worlds-first-remotely-operated-commercial-vessel.aspx

158 www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx

159 www.cml.fraunhofer.de/en/researchprojects/current-projects.html

- In The Netherlands, the Research Lab Automated Shipping will open in March 2019. Infrastructure (inland water and port) and support from scientists will be available for every experimenting party.

- The AAWA (Advanced Autonomous Waterborne Applications Initiative) project was a joint industry-academia project that explores the preconditions for autonomous shipping[160].

- The Design for Value (D4V) program focused on door-to-door supply chain, which is under digital disruptions and is rapidly changing towards an ecosystem of fully autonomous system-of-systems[161].

- In Denmark there are research projects: "Electronic lookout - Comparing Human Performance with a Robotic Solution" and "Autonomous Situation Awareness at Sea".

- Sesame Solution II aims to develop and productify a complete e-navigation system[162].

- SEAFAR is an industrial initiative developing technology to remotely operate automated barges for inland shipping covering integration of technology, remote operating of barges from a shore control centre, in combination with a mobile intervention unit and barge management[163].

- The Laessi research project focused on developing guidance and assistance systems for increasing the safety of navigation on inland waterways.[164]

- Green Deal COBALD project is aiming at reducing IWT emissions through digitalisation[165].

- Riverguide is also an IWT tool[166].

- Captain AI reduces the need for real world training through virtual simulation[167].

- ROMAS (Remote Operations of Machinery and Automation Systems) is a Norwegian research project for on-shore engine control room technology.

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[160] www.utu.fi/en/units/ccr/examples/Pages/AAWA.aspx
[161] http://d4value.dimecc.com/
[162] http://sesamesolution2.org/
[163] www.seafar.eu/
[164] www.innovative-navigation.de/en/allgemein-en/impressive-final-presentation-of-the-collaborative-research-project-laessi/
[165] www.greendeals.nl/green-deals/cobald
[166] http://riverguide.eu/
[167] www.captainai.com/about/

- SIMAROS (Safe IMplementation of Autonomous and Remote Operation of Ships) is a Norwegian research project for developing and assuring technical solutions for autonomous and remote-controlled navigation [168].

- Autosea is a Norwegian research program on sensor fusion and collision avoidance.[169]

- Transport 2025 program highlights the Research Council of Norway's new strategic focus on research and innovation within the transport domain. It incorporates a systemic perspective on the transport system viewed as a whole[170].

- The ENERGIX program aims for greener shipping[171].

- The research program Green coastal shipping aims at exactly what the name says[172].

- Research project Humane – research project that aims to discuss the need for new and different skills.

- IMO - Human Centred Design project.

- Project MAXCMAS aims to demonstrate autonomous control of an USV for mine counter measure operations and develop broader USV applications along with navigational support for larger conventional vessels[173].

- INNOSBZ is a Polish sectorial program aimed at increasing the competitiveness and innovativeness of the Polish sector of unmanned systems production on the global market in the perspective of 2023/2026. Waterborne is one of the thematic areas on INNOSBZ.

- Business Finland has launched an EUR 100 m programme for Smart Mobility aiming at Finland being recognized as leading country of smart logistics & mobility systems, including autonomous “from Forest to Sea” logistics[174].

- ÄlyVESI - Smart City Ferries - Project developed and tested new solutions and services for the intelligent transport of mass traffic in urban waterways[175].

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[168] www.globalpsa.com/autonomous-ships/
[169] www.ntnu.edu/amos/autosea
[170] www.forskningsradet.no/prognett-transport/Home_page/1253996640735
[171] www.forskningsradet.no/prognett-energix/Home_page/1253980140022
[172] www.dnvgl.no/maritime/gront-kystfartsprogram/index.html
[173] www.warsashacademy.co.uk/about/our-expertise/maritime-research-centre/project-maxcmas/home.aspx
[174] www.businessfinland.fi/en/whats-new/news/2018/smart-mobility-program-starts/
[175] www.aboamare.fi/About-%c3%84lyVESI

Of the classification societies, at least Lloyd's Register, Bureau Veritas, DNV GL and American Bureau of Shipping have all come out with codes or guidelines for autonomous shipping[176]. Regarding regulation and standardisation, the following efforts have been initiated:

- IMO (regulatory scoping exercise goes through the regulations to see if they are applicable to the use of automated and remote-controlled technologies, and if not, what should be changed)[177].
- EMSA[178] addresses maritime safety in general.
- DG MOVE[179] ad-hoc Working Group of the High-Level Steering Group on Vessel Traffic Monitoring is analysing the consequences of MASS for the VTS operations and operators.
- Different national developments in Norway, Finland, Denmark, Japan, Korea and China; Belgium and The Netherlands are addressing regulation in the framework of the joint test area IWT. The national developments mainly enable automated technologies for testing purposes.
- UNECE working groups are addressing WP for CAT through harmonisation.
- PIANC working group smart shipping is working on infrastructure[180].
- Central Commission for the Navigation of the Rhine (CCNR) works on levels of automation for inland waterways[181].
- For inland navigation the standards (vessel, qualification/crew and information technologies) are developed under CESNI for EU and CCNR.[182]
- Specific shipping (open) standard initiatives such as SHIPDEX on data exchange for ship maintenance[183].
- ETF (European Transport workers' Federation) has made a plea for a human-centred approach to automation in shipping[184].

[176] See e.g. here: http://www.bureauveritas.jp/news/pdf/641-NI_2017-12.pdf or http://rules.dnvgl.com/docs/pdf/dnvgl/cg/2018-09/dnvgl-cg-0264.pdf
[177] http://www.imo.org/en/mediacentre/pressbriefings/pages/08-msc-99-mass-scoping.aspx
[178] http://www.emsa.europa.eu/
[179] ec.europa.eu/info/departments/mobility-and-transport_en
[180] www.pianc.org/
[181] ccr-zkr.org/
[182] www.cesni.eu/
[183] http://www.shipdex.org/
[184] www.etf-europe.org/resource/etf-plea-for-a-human-centred-approach-to-automation-in-shipping/

# 6 Research and Innovation Initiatives

*In this chapter, the structure of the roadmap, consisting of thematic areas, R&I initiatives and actions is explained, and the content is presented. The implementation plan results from consultations with multiple stakeholders from European Commission, Member States governments, industry and academia. The assessments of timing, priority, responsibility, links and accelerators they made are summarized for a high-level, comparative analysis at the level of initiatives*

## *6.1 Description of the STRIA process*

The assessments for the implementation plan are structured into three key elements, being thematic areas, R&I initiatives and actions.

Thematic areas are the division of themes for research and innovation in field of connected and automated waterborne traffic. In total 9 thematic areas have been proposed.

R&I initiatives are concrete activities and undertakings to be implemented by stakeholders to achieve the European Union's goals of connected and automated waterborne traffic. They are described in terms of objectives, state of the art challenges as well as impacts. There are usually several initiatives per thematic area.

Actions describe in sequence the content, timing, instruments and responsibilities of all activities that must implemented within each of the R&I initiatives. They are summarized in action sheets (one per initiative).

The thematic areas were defined from previous analysis, adjusting the thematic areas decided upon by other traffic modes to the needs of the waterborne sector. They were verified, and the lists of initiatives and actions result from an intense stakeholder dialogue involving Member States representatives and experts from industry and academia.

## *6.2 Thematic Areas and List of R&I Initiatives*

A list of the thematic areas and R&I initiatives from the action sheets can be seen in table 12.

*Table 12. List of thematic areas and R&I actions*

| Thematic Areas | R&I Initiatives |
|---|---|
| **1. In-vessel Enablers** | 1.1 Develop and demonstrate modular technologies for smart, connected and automated ships aiming at enabling new, safe, reliable and efficient business models |
| **2. Condition and Operational Monitoring** | 2.1. Valorising and optimising condition data for failure prediction and optimal operations |
| | 2.2. Valorising and optimising cargo and crew data for optimal and safe operations |
| **3. Validation & Large-scale demonstration** | 3.1. Enable first deployment of smart, connected autonomous waterborne infrastructure and vessel solutions |
| | 3.2. Enable first deployment of piloting at a distance and remote-control harbour services |
| **4. Information Exchange and certificates** | 4.1. Support regulatory development/adaptation to remote controlled and autonomous shipping |
| | 4.2. Develop and validate/demonstrate standards for cross platforms electronic information sharing |
| | 4.3. Develop and demonstrate shore-based fleet operation centres and/or IoT adaptation of ship's systems & components to exploit increasing connectivity |
| **5. Socio-Economic impact of CAT** | 5.1. Assessment of the socio-economic impact of connected and automated/autonomous shipping (CAT) |
| | 5.2. Assessment of risk, public and stakeholder acceptance |
| **6. Changed Working Conditions** | 6.1. Future expert |
| | 6.2. Joint activity in distributed teams |
| | 6.3. Teaming with increasing automation (human-machine interaction) / Human-centred design of maritime automation |
| **7. Physical & Digital Infrastructure** | 7.1. Robust traffic management and Port Interaction |
| | 7.2. Complimenting the physical with the digital |
| **8. Big Data, AI and their Applications** | 8.1. AI for improved situation awareness |
| | 8.2. AI to mine value from the big data |
| **9. Secure connectivity** | 9.1. Ensuring the security and safety of automated and connected shipping and maritime logistics |

More information on the thematic areas and R&I initiatives can be found in the action sheets (see reference document).

## *6.3 Assessments of the Initiatives: Priority, Timing, Responsibility, Links*

Prior to an in-depth consideration of the actions defined for each initiative, a comparative assessment of the initiatives themselves is given. This analysis is based on voting and discussions among the stakeholders from European Commission, Member States, industry and academia involved in the process of drafting the plan at hand. Inevitable, it is biased by the composition of the group, which leaned more towards public authorities and academia, rather than industrial stakeholders. Also, due to different thematic focusing and width of content, the initiatives are not always easy to compare. The priority rankings in the individual action sheets may differ from these ones.

*Table 13. Ranking of importance of the initiatives*

| Importance ranking | # | Short title of initiative |
|---|---|---|
| 1. | 1.1. | Develop and demonstrate modular technologies |
| 2. | 9.1. | Ensuring the security and safety |
| 3. | 3.1. | Enable first deployment of infrastructure & vessel solutions |
| | 4.1. | Support regulatory development |
| 4. | 6.1. | Future experts |
| 5. | 4.2. | Develop standards for electronic information sharing |
| | 8.1. | AI for improved situation awareness |
| 6. | 5.1. | Assessment of a business case |
| 7. | 4.3. | Develop fleet operation centres or IoT adaptation of ships systems |
| | 5.2. | Assessment of Risk levels |
| | 7.1. | Robust traffic management and Port Interaction |
| | 7.2. | Replacing the physical with the digital |
| 8. | 6.2. | Joint activity in distributed teams |
| 9. | 2.1. | Valorising and optimizing condition data |
| | 6.3. | Teaming with increasing automation |
| | 8.2. | AI to mine value from the big data |
| 10. | 2.2. | Valorising and optimising cargo and crew data |
| | 3.2. | Enable first deployment of piloting at a distance |

The four initiatives that were considered the most important (see table 13, marked in red), were considered that in the discussions in the groups as well. They are considered the most important initiatives to ensure future development and deployment of automated and connected waterborne solutions. The two initiatives considered least important (marked yellow) were rather narrow in their scope, which probably contributed to their importance ranking. The initiatives between these extremes (marked in orange) should probably be of similar importance.

Regarding the Priority Rankings of Initiatives, the stakeholders confirmed that despite of the result of the ranking all initiatives would be highly relevant for enabling connected and automated waterborne traffic. It was, however, agreed that the most important ones are essential for the realization of connected and automated waterborne traffic.

The timing of the various initiatives was discussed in the workshops. The information in the table below, was directly derived from the action sheets. Actions on a short time scale are completed until 2023, whereas medium lasted until 2030. Long term actions may take beyond 2030. In general, it seemed that most initiatives were considered short term.

*Table 14. Timing per initiative*

| # | Short title of initiative | Short term | Mid term | Long term |
|---|---|---|---|---|
| 1.1. | Develop and demonstrate modular technologies | | | |
| 2.1. | Valorising and optimizing condition data | | | |
| 2.2. | Valorising and optimising cargo and crew data | | | |
| 3.1. | Enable first deployment of infrastructure & vessel solutions | | | |
| 3.2. | Enable first deployment of piloting at a distance | | | |
| 4.1. | Support regulatory development | | | |
| 4.2. | Develop standards for electronic information sharing | | | |
| 4.3. | Develop fleet operation centres or IoT adaptation of ships systems | | | |
| 5.1. | Assessment of a business case | | | |
| 5.2. | Assessment of Risk levels | | | |
| 6.1. | Future experts | | | |
| 6.2. | Joint activity in distributed teams | | | |
| 6.3. | Teaming with increasing automation | | | |
| 7.1. | Robust traffic management and Port Interaction | | | |
| 7.2. | Replacing the physical with the digital | | | |
| 8.1. | AI for improved situation awareness | | | |
| 8.2. | AI to mine value from the big data | | | |
| 9.1. | Ensuring the security and safety | | | |

The darker colour in table 14 indicates the primary timing, but in some cases some actions within an initiative had different timings (for specific timing see the action sheets in the reference documents), and then the darker is the dominant one. In general actions that have already been somehow initiated or are considered important pre-requisites were chosen for short term deployment. As the waterborne traffic has embraced connected and automated technologies at a rapid pace in recent years, there is an urgency that requires that a lot of development is done simultaneously.

A part of the comparative assessment of the initiatives was to vote for what parties should be the ones implementing the actions, and what parties should fund the action. This analysis is based on voting and discussions among the stakeholders from European Commission, Member States, industry and academia involved in the process of drafting the plan at hand. Again, this evaluation is probably biased due to the composition of the group, but it might give some guidelines. The results in this table may also differ somewhat from the allocations in the action sheets.

*Table 15. Responsibilities per initiative*

| # | Short title of initiative | Implementation | Funding |
|---|---|---|---|
| 1.1. | Develop and demonstrate modular technologies | I | I, EU |
| 2.1. | Valorising and optimizing condition data | I, EU | I, EU |
| 2.2. | Valorising and optimising cargo and crew data | I, MS, EU, Int. | I, EU |
| 3.1. | Enable first deployment of infrastructure & vessel solutions | I, MS, SB/WW, EU | EU |
| 3.2. | Enable first deployment of piloting at a distance | I, MS, SB/WW, EU, Int. | MS, SB/WW, EU |
| 4.1. | Support regulatory development | I, MS, SB/WW, EU, Int. | MS, EU, Int. |
| 4.2. | Develop standards for electronic information sharing | I, Int. | EU, Int. |
| 4.3. | Develop fleet operation centres or IoT adaptation of ships systems | I, MS, EU | I, EU, Int. |
| 5.1. | Assessment of a business case | I, EU, Int. | I, EU |
| 5.2. | Assessment of Risk levels | I, EU, Int. | EU, Int. |
| 6.1. | Future experts | I, MS, EU | I, MS, EU |
| 6.2. | Joint activity in distributed teams | I, EU, Int. | I, EU |
| 6.3. | Teaming with increasing automation | I, EU | I, EU |
| 7.1. | Robust traffic management and Port Interaction | MS, SB/WW, EU | MS, SB/WW, EU |
| 7.2. | Replacing the physical with the digital | I, MS, EU, Int. | MS, EU |
| 8.1. | AI for improved situation awareness | I, EU | I, EU |
| 8.2. | AI to mine value from the big data | I | I, EU |
| 9.1. | Ensuring the security and safety | I, MS, SB/WW, EU, Int. | MS, EU, Int. |

I = Industry
MS = Member State
SB/WW = Sea Basin, Waterway
EU = European Union
Int. = International

From table 15 it seems that the workshop participants felt that there should be EU funding on all the initiatives, however, even other sources were suggested. It would feel natural to consider industry funding especially for the initiatives, where the industry was implementing the work and has been suggested as someone providing funding. Also, for the more local projects MS would probably be the more natural party to fund the initiatives.

The initiatives were interlinked in many ways, sometimes one initiative was a prerequisite to another and other times two initiatives were intertwined. It was of course natural that e.g. the deployment projects were interlinked. Table 16 aims to demonstrate these interdependencies.

*Table 16. Links between the initiatives*

| | # | 1.1. | 2.1. | 2.2. | 1.1. | 2.1. | 2.2. | 3.1. | 3.2. | 4.1. | 4.2. | 4.3. | 5.1. | 5.2. | 6.1. | 6.2. | 6.3. | 7.1. | 7.2. | 8.1. | 8.2. | 9.1. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Given input to | 1.1. | | | | | | | | | | | | | | | | | | | | | |
| | 2.1. | | | | | | | | | | | | | | | | | | | | ■ | |
| | 2.2. | | | | | | | | | | | | | | ■ | | | ■ | | | | |
| | 3.1. | | | | | | | | | ■ | ■ | ■ | ■ | | | | | ■ | ■ | | | |
| | 3.2. | | | | | | | | | | | ■ | | | | | | | ■ | | | |
| | 4.1. | | | | | | | ■ | | | | ■ | | | | | | | | ■ | | |
| | 4.2. | ■ | | | | | | ■ | | ■ | | ■ | | | | | | ■ | | | | ■ |
| | 4.3. | | | | | | | ■ | ■ | ■ | | | | | | | | | ■ | | | |
| | 5.1. | | | | | | | ■ | | | | | | | ■ | ■ | ■ | ■ | | | | |
| | 5.2. | | | | | | | | | | | | | | | | | | | | | |
| | 6.1. | | | ■ | | | | | | | | | ■ | | | | | | | ■ | | |
| | 6.2. | | | | | | | | | | | | ■ | | | | | | | | | |
| | 6.3. | | | | | | | | | | | | ■ | | | | | | | | | |
| | 7.1. | | | | | | ■ | ■ | | | ■ | | ■ | | | | | | | | | ■ |
| | 7.2. | | | | | | | ■ | ■ | | | ■ | | | | | | | | | | |
| | 8.1. | | | | | | | | | ■ | | | | | ■ | | | | | | | |
| | 8.2. | | ■ | | | | | | | | | | | | | | | | | | | |
| | 9.1. | | | | | | | | | | ■ | | | | | | | ■ | | | | |

# 7 Action Plan

*In this chapter, a comprehensive plan based on action plan assessments is presented. An emphasis is put on opportunities for accelerating the innovation process through agile methodology, complementarity and coherence. The actions are timed and sorted for interdependencies. The more thorough descriptions of the actions can be found in the action sheets in the reference documents. It should also be noted that many of the stakeholders called for a more cross-discipline approach, rather than scattered over several thematic areas and actions.*

## *7.1 Comprehensive plan based on the action plans*

In the following, the actions suggested by the involved stakeholders for the various initiatives of the nine thematic fields are summarized (see table 17). The content in terms of action descriptions, instruments, responsibilities for implementation and founding sources has been extracted from dedicated action sheets. For better comparability, each action has been reduced to a very brief description of the main ideas. For some areas when there has been no input in the action sheets, the result from the general voting, mentioned earlier, has been used.

*Table 17. Action plan*

| # | Thematic field | Instrument | Timing | Implement. | Funding |
|---|---|---|---|---|---|
| 1. | **In-vessel enablers** | | | | |
| 1.1. | *Develop and demonstrate modular technologies for smart, connected and automated ships* | | | | |
| 1.1.1. | Integration of digital solutions onboard | IA | Short/med. | I | I & EU |
| 1.1.2. | Resiliency of the digital infrastructure to failure | R&I | Short/med. | I | I & EU |
| 2. | **Condition and operational monitoring** | | | | |
| 2.1. | *Valorising and optimising condition data for failure prediction and optimal operations* | | | | |
| 2.1.1. | Failure prediction | | Short | I & EU | I & EU |
| 2.1.2. | Transfer of enhanced information of the vessel's dynamic status | | Short/med. | I & EU | I & EU |
| 2.2. | *Valorising and optimising and sharing of cargo and crew data for optimal and safe operations* | | | | |
| 2.2.1. | Monitoring, infrastructure sharing and capturing information on status of cargo and passenger groups | | Medium | I, MS, EU, Int. | I & EU |
| 2.2.2. | Monitoring of living environments and general health situation of passengers and seafarers | | Long | I, MS, EU, Int. | I & EU |
| 3. | **Validation & large-scale demonstration to enable deployment** | | | | |
| 3.1. | *Enable first deployment of smart, connected autonomous waterborne infrastructure and vessel solutions* | | | | |
| 3.1.1. | Design, build and test the required infrastructure for autonomous waterborne traffic | | Short | CEF, Member States | EU |
| 3.1.2. | To create a completely autonomous vessel | | Short | CEF, Member States | EU |
| 3.2. | *Enable first deployment of piloting at a distance and remote control harbour services* | | | | |
| 3.2.1. | Demonstrate E-Pilotage, enabling piloting at a distance | | Short | RTD | MS, SB/WW, EU |
| 4. | **Electronic Information Exchange and Certification** | | | | |
| 4.1. | *Pre- normative research: support regulatory development/adaptation to remote controlled and autonomous shipping* | | | | |
| 4.1.1. | Certification for safety, security requirements | CSA | Short | MS, EU | € 3 M |
| 4.1.2. | Identification of the acceptance criteria for future autonomy or remote control | CSA | Medium | MS, EU | MS, EU, Int. |
| 4.1.3. | Testing, certification, approval of the various CAT systems | RIA | Med./long | I | MS, EU, Int. |
| 4.2. | *Standardisation/ best practice: develop and validate/demonstrate standards for cross platforms electronic information* | | | | |
| 4.2.1. | Identification of existing (best) practices and/or used models for electronic exchange of information | CSA | Short | EU | EU, Int. |
| 4.2.2. | Enabling the Digital Twin of the ship | RIA | Short | I | EU, Int. |
| 4.2.3. | Demonstration of common/complementary data sharing mechanisms | DEMO | Medium | I, MS, EU | EU, Int. |
| 4.3. | *Smart shipping: develop and demonstrate shore-based fleet operation centres and/or IoT adaptation of ships systems* | | | | |
| 4.3.1. | Smart Ships | DEMO | Long | EU | I, EU, Int. |
| 4.3.2. | Smart Ports | DEMO | Long | MS | I, EU, Int. |
| 4.3.3. | Smart fairways | RIA | Long | MS, EU | I, EU, Int. |
| 5. | **Socio-Economic impact of CAT** | | | | |
| 5.1. | *Assessment of the socio-economic impact of connected and automated/autonomous shipping (CAT)* | | | | |
| 5.1.1. | High level assessment = 3 layers | R and I and collaboration | Short | Technology Platform | I, EU |
| 5.2. | *Assessment of risk, public and stakeholder acceptance* | | | | |
| 5.2.1. | Defining societal risk acceptance | RIA | Medium | I, EU, Int. | EU, Int. |
| 5.2.2. | Assessment of new risks (in system perspective) | RIA | Medium | I, EU, Int. | EU, Int. |
| 5.2.3. | Assessment of vessel and passenger safety, vessel connectivity and cybersecurity issues | | Medium | I, EU, Int. | EU, Int. |
| 6. | **Changed working conditions (earlier: Human factors)** | | | | |
| 6.1. | *Future expert* | | | | |
| 6.1.1. | Identification of new functions and new skills which may appear during the evolution of growing automation | RIA | Medium | I, MS, EU | I, MS, EU |
| 6.1.2. | Study of how cross-sectorial jobs sharing/pooling can be supported organisationally, legally, socially | CSA | Medium | I, MS, EU | I, MS, EU |
| 6.1.3. | Validation, testing small scale pilot study | RIA | Medium | I, MS, EU | I, MS, EU |

| # | Thematic field | Instrument | Timing | Implement. | Funding |
|---|---|---|---|---|---|
| 6.2. | *Joint activity in distributed teams* | | | | |
| 6.2.1. | Describe the actors in future scenarios and study how the roles should distribute and share or allocate control, authority, responsibility etc. | RIA | Medium | I, EU, Int. | I, EU |
| 6.2.2. | Explore which support in form of hard/software, communications infrastructure and policy is needed for the challenges | RIA | Medium | I, EU, Int. | I, EU |
| 6.3. | *Teaming with increasing automation (human-machine interaction) / Human-centered design of maritime automation* | | | | |
| 6.3.1. | Analysis of Human behaviour in mixed traffic (manned and unmanned ships) | RIA | Short | I, EU | I, EU |
| 6.3.2. | Conception and design of technology/automation that is standardised and transparent in its behaviour to support joint activity with humans | RIA | Short | I, EU | I, EU |
| 6.3.3. | Identify the information/data needed to be 'transmitted' between human and machine | RIA | Short | I, EU | I, EU |
| 7. | **Physical & Digital Infrastructure** | | | | |
| 7.1. | *Robust traffic management and Port Interaction* | | | | |
| 7.1.1. | International standards development for: shore remote control centres, inland waterway physical infrastructure and common data transfer protocols across proprietary systems | | Medium | MS, SB/WW, EU | MS, SB/WW, EU |
| 7.1.2. | For waterborne transport, analysis of digital infrastructure resilience and risks, strategies to overcome. | | Medium | MS, SB/WW, EU | MS, SB/WW, EU |
| 7.2. | *Complimenting, the physical with the digital* | | | | |
| 7.2.1. | Smart port and fairway monitoring devices | RIA | Long | EU/MS | MS, EU |
| 7.2.2. | Connected and Automated Port infrastructure for automated shipping | | Long | I, MS, EU, Int. | MS, EU |
| 8. | **Big Data, AI and their applications** | | | | |
| 8.1. | *AI for improved situation awareness* | | | | |
| 8.1.1. | Development of advanced algorithms, machine vision, decision support systems that, for example, use AI systems for waterborne safe navigation at sea and on inland waterways | | Short/med. | I, EU | I, EU |
| 8.1.2. | Providing evidence and proof for safe AI-based operation | | Short/med. | I, EU | I, EU |
| 8.2. | *AI to mine value from the big data* | | | | |
| 8.2.1. | Combination of multiple data sources to use past experience to optimise operations | | Short | I | I, EU |
| 8.2.2. | Using AI to analyse global historic AIS data to identify near misses and link to specific operations, accident hot spots and other potential causes | | Short | I | I, EU |
| 8.2.3. | Using big data to monitor overall compliance with regulatory environmental requirements | | Short | I | I, EU |
| 8.2.4. | Linking big economic data, to better predict investment decisions for port and inland waterway infrastructure | | Short | I | I, EU |
| 9. | **Secure Connectivity** | | | | |
| 9.1. | *Ensuring the security and safety of automated and connected shipping and maritime logistics* | | | | |
| 9.1.1. | Integrated and secure communication architecture for autonomous and connected waterborne transport | RIA | Short/med. | I & research | MS, EU, Int. |
| 9.1.2. | Stakeholder liaison and standards establishment | CSA | Short/med. | I & research & authorities | MS, EU, Int. |

## *7.2 Actions for the European Commission*

As can be seen in the table above, it was suggested that the European Commission Participate in all projects, at least in the funding. However, there are certain actions that should probably be led by the European Commission. The following is a list of proposed EU actions divided timing-wise.

<u>Short term actions</u>

**5.1.1.** High level assessment = 3 layers (Interlinked with 3.1., 6.1., 6.2., 6.3., 7.1.)

**3.1.1.** Design, build and test the required infrastructure for autonomous waterborne traffic (Interlinked with 4.1., 4.2., 4.3., 5.1., 7.1., 7.2.)

**3.1.2.** To create a completely autonomous vessel (Interlinked with 4.1., 4.2., 4.3., 5.1., 7.1., 7.2.)

**4.2.1.** Identification of existing (best) practices and/or used models for electronic exchange of information (To give input to 1.1., 4.1., 4.3. interlinked with 3.1., 7.1., 9.1.)

**4.2.3.** Demonstration of common/complementary data sharing mechanisms (To give input to 1.1., 4.1., 4.3. interlinked with 3.1., 7.1., 9.1.)

**4.3.1.** Smart Ships (Interlinked with 3.1., 3.2., 4.1., 7.2.)

<u>Medium term actions</u>

**5.2.1.** Defining societal risk acceptance

**5.2.2.** Assessment of new risks (in system perspective)

**5.2.3.** Assessment of vessel and passenger safety, vessel connectivity and cybersecurity issues

**6.1.1.** Identification of new functions and new skills which may appear during the evolution of growing automation (Interlinked with 2.2., 5.1., 8.1.)

**6.1.2.** Study of how cross-sectorial jobs sharing/pooling can be supported organisationally, legally, socially (Interlinked with 2.2., 5.1., 8.1.)

**6.1.3.** Validation, testing small scale pilot study (Interlinked with 2.2., 5.1., 8.1.)

## *7.3 Actions for Member States*

The actions that the MS should at least take main responsibility for, are the following. The list is of proposed MS actions divided timing-wise.

<u>Short term actions</u>

**3.2.1.** Demonstrate E-Pilotage, enabling piloting at a distance (Interlinked with 4.3., 7.2.)

**2.2.1.** Monitoring, infrastructure sharing and capturing information on status of cargo and passenger groups (Interlinked with 6.1. to give input to 7.1.)

**2.2.2.** Monitoring of living environments and general health situation of passengers and seafarers (Interlinked with 6.1. to give input to 7.1.)

<u>Medium term actions</u>

**4.1.1.** Certification for safety, security requirements (Interlinked with 3.1., 4.3. 8.1.)

**4.1.2.** Identification of the acceptance criteria for future autonomy or remote control (Interlinked with 3.1., 4.3. 8.1.)

**7.1.1.** International standards development for: shore remote control centres, inland waterway physical infrastructure and common data transfer protocols across proprietary systems (Interlinked with 2.2., 3.1., 4.2., 5.1., 9.1.)

**7.1.2.** For waterborne transport, analysis of digital infrastructure resilience and risks, strategies to overcome. (Interlinked with 2.2., 3.1., 4.2., 5.1., 9.1.)

<u>Long term actions</u>

**4.3.2.** Smart Ports (Interlinked with 3.1., 3.2., 4.1.,7.2.)

**4.3.3**. Smart fairways (Interlinked with 3.1., 3.2., 4.1.,7.2.)

**7.2.1.** Smart port and fairway monitoring devices (Interlinked with 3.1., 3.2., 4.3.)

**7.2.2.** Connected and Automated Port infrastructure for automated shipping (Interlinked with 3.1., 3.2., 4.3.)

## *7.4 Actions for others*

There were other actors that were suggested as implementors, however, other than MS and EU, based on the work in the workshops only the industry seems like a credible partner to take the lead in certain cases. The industry is certainly equipped to take actions faster.

<u>Short term actions</u>

**2.1.1.** Failure prediction (Interlinked with 8.2.)

**2.1.2.** Transfer of enhanced information of the vessel's dynamic status (Interlinked with 8.2.)

**8.2.1.** Combination of multiple data sources to use experience to optimise operations (Interlinked with 2.1.)

**8.2.2.** Using AI to analyse global historic AIS data to identify near misses and link to specific operations, accident hot spots and other potential causes (Interlinked with 2.1.)

**8.2.3.** Using big data to monitor overall compliance with regulatory environmental requirements (Interlinked with 2.1.)

**8.2.4.** Linking big economic data, to better predict investment decisions for port and inland waterway infrastructure (Interlinked with 2.1.)

**6.3.1.** Analysis of Human behaviour in mixed traffic (manned and unmanned ships) (Interlinked with 5.1.)

**6.3.2.** Conceptualisation and design of technology/automation that is standardised and transparent in its behaviour to support joint activity with humans (Interlinked with 5.1.)

**6.3.3.** Identify the information/data needed to be 'transmitted' between human and machine (Interlinked with 5.1.)

**4.2.2.** Enabling the Digital Twin of the ship (To give input to 1.1., 4.1., 4.3., interlinked with 3.1., 7.1., 9.1.)

**9.1.1.** Integrated and secure communication architecture for autonomous and connected waterborne transport (Interlinked with 4.2., 7.1.)

**9.1.2.** Stakeholder liaison and standards establishment (Interlinked with 4.2., 7.1.)

**8.1.1.** Development of advanced algorithms, machine vision, decision support systems that, for example, use AI systems for waterborne safe navigation at sea and on inland waterways (Interlinked with 4.1., 6.1.)

**8.1.2.** Providing evidence and proof for safe AI-based operation (Interlinked with 4.1., 6.1.)

**1.1.1.** Integration of digital solutions onboard

**1.1.2.** Resiliency of the digital infrastructure to failure

<u>Medium term actions</u>

**4.1.3.** Testing, certification, approval of the various CAT systems (Interlinked with 3.1., 4.3. 8.1.)

**6.2.1.** Describe the actors in future scenarios and study how the roles should distribute and share or allocate control, authority, responsibility etc. (Interlinked with 5.1.)

**6.2.2.** Explore which support in form of hard/software, communications infrastructure and policy is needed for the challenges (Interlinked with 5.1.)

# 8 Conclusions and Recomendations

One of the most important conclusions that arose from this roadmap work, was the need to emphasize the integration of traffic modes to unlock the full potential of connected and automated waterborne traffic. A joint vision of connected and automated traffic is needed on an EU and even international level. Cross-border cooperation between member states is needed both for regulation and to ensure smooth information transfer between areas and traffic modes. IWT must be included in the automated and connected efforts so that the goals of EU can be achieved. Future EU calls need to address the whole multimodal logistics chain.

Continuous skill development on EU level is crucial so that the waterborne companies can hold on to the market and forerunner position that they currently hold. Important skills are cyber security, AI and digitalisation etc. EU can also stay at the forefront of societal and ethical issues that need to be addressed during the development. The EU and the MS must focus on training and Intellectual Property Rights (IPR) protection issues of both data and technologies to ensure the competitive edge.

From the priority rankings in the report, we can see the actions that the process participants considered most important. The initiative *1.1. Develop and demonstrate modular technologies* was considered the most important. The actions, under the initiative, deal with integration of information and information flow. There is still much to do on the waterborne side with transferring all data electronically and use of APIs to enable different systems to communicate with each other within waterborne and between traffic modes. Such efforts together with applying much more standardisation to the different value propositions within waterborne would revolutionize waterborne logistics.

The second highest priority was given to *9.1. Ensuring the security and safety* of the solutions. This is crucial with new technologies that are being developed and deployed fast. *3.1. Enabling first deployment of infrastructure & vessel solutions* was third on the priority list. Such a demonstration would be the best way for EU to accelerate the development, it could demonstrate the financial benefits of the solution and prove the viability of the technical concept. The fourth item on the priority list, was to *4.1. Support the regulatory development.* This is very important, as this has been identified as one of the major challenges for automated and connected solutions on the waterborne side. The MS have a major role to play here, as waterborne regulations are usually developed on an international level, where the MS speak for EU. EU coordination is increasing even in this area.

The fast development pace in recent years in connected and automated solutions for waterborne has been driven by the industry. The industry developing the products, have often informed the wider circles of authorities and academia at the introduction or deployment of new products or services. Existing funding programs have been too slow to respond to the needs of the industry and the IPR issues have been difficult in consortiums, as the companies jumped right in to developing their offerings for connected and automated waterborne traffic. Therefore, it is only fitting that two of the four

(1.1. and 9.1.) of the initiatives with the highest priority are proposed to be driven forward by the industry.

The EC should consider ways to fund the development at a faster pace. Currently external funding for the development has mainly come from the MS. It must also be remembered that the Industry has invested heavily in the development. There are still many issues for the academia to research, even if the technical solutions are coming at a faster pace than expected. The societal issues are important for the implementation of the technologies, and the companies currently developing connected and automated technologies probably do not have the time to devote enough research to those issues.

This document holds action lists for the EU, MS and industry, together with rough schedules and the interdependencies of the efforts. As the development is advancing at a breath-taking speed, the schedule for the actions is very much on the earlier part of the planned time. Now is the time for the EC to emphasize the needs of the waterborne industry, to ensure that the head-start that the European industries have managed to get, can be turned into actual new jobs and business on a European level. This is easily justified, as these technologies are at the same time decreasing emissions and road congestion and improving the safety and working conditions of waterborne personnel.

# PART IV:

# CONCLUSIONS ON CROSS-MODAL INTERACTIONS IN CAT

The three transport modes considered in this roadmap, road, rail and waterborne transport, and likewise aviation, do not only refer to fundamentally different spatial dimensions but also in most cases imply differences in the technologies for the transport modes and physical infrastructures, and in terms of the frameworks for human interaction, the business, and legal frameworks. They also serve different purposes in the mobility of people and goods and their place in society. Therefore, the concepts and approaches for the introduction of connected and automated transport (CAT) in those modes is different. This is clearly reflected in the initiatives and actions of the roadmaps outlined in this document. It would make little sense to seek a general alignment of innovation processes and related support measures at that level.

Nonetheless, the descriptions of the challenges and hurdles in the mode-specific roadmaps of this implementation plan also reveal that CAT means a transformation that is enabled by advancements in digital technologies such as smart electronic control systems, environment perception, precise actuation, and AI-supported decision making as well as by connecting vehicles / vessels and infrastructures with data networks and the cloud. Thereby, CAT implies more systemic solutions affecting the concept of sharing responsibility between human and technology-based control in all transport modes considered in a comparable way.

The extent to which this means change is indeed different for the various transport modes. As the railways (and also aviation) have merely followed a top-down safety logic, CAT is rather an evolutionary development there, while in the road and waterborne transport sectors with their traditionally bottom-up safety logic, it implies a more fundamental or disruptive paradigm shift. At the same time, the similarities at the level of the enabling digital technologies and concepts suggest a potential for mutual transfer of knowledge and experiences in the development of enabling technologies and concepts for CAT.

It should also be noted that the various transport modes do not exist in silos but frequently interact and need to cooperate efficiently, in order to enable a seamless travel experience for people or a timely delivery of goods. Due to the similarity of digital technologies enabling CAT, the interfaces between the modes may be improved, and even new solutions may arise, e.g. from the concept of Mobility-as-a-Service (MaaS). An example would be self-driving shuttle buses providing an on-demand and on-time last-mile connection from a train station in a remote location.

CAT is more than connected and automated driving and passenger transport, it also includes automated cooperative logistics along multi-modal chains enabled by digital and physical connectivity between transport modes, and automated zone access, control and management (such as sea traffic management, road traffic safety and low emission zones).

It would also be important to foster the skill development at EU level to establish solid relationship between different knowledge fields and transport sector (aviation, rail, road and waterborne) to generate synergy and lead the change to integrated CAT.

Therefore, to conclude the analysis described in this document, cross-modal links, transfer potentials and new opportunities shall be described, and measures for the support of innovation related to them shall be outlined in the following.

Cross Modal Links

Issues relevant for CAT in the different modes considered include:

- Combination of sensors with AI in environment perception
- Connectivity and data communication with digital infrastructures
- Cyber security and functional safety of control systems
- Human factors in the sharing of tasks between drivers/pilots and machines
- Universal design and user acceptance
- Testing and validation
- Socio-economic impact assessment
- Backwards compatibility
- Harmonization and standardization
- Liability and regulatory issues

Transfer Potentials

In view of the similarity of the enabling digital technologies and concepts of CAT and the relevance of common issues of CAT in the different modes, and considering the different pace and timing of innovation as outlined in this roadmap, leads to various opportunities for the transfer of technologies and experiences as summarized in the table 18.

*Table 18: Examples of technology and experience transfer potentials in CAT*

| To.. From.. | Road | Rail | Water | Air |
|---|---|---|---|---|
| **Road** | | Environment Perception, V2X Communication | V2V Communication | Automated Control Systems for Drones, Navigation and Maps |
| **Rail** | Top-Down Safety Concepts | | | |
| **Water** | Cyber secure connectivity | | | Dynamic Maps |
| **Air** | Fail-Operation | Human-Machine Interface, Positioning | Human-Machine Interface | |

New Opportunities

Particularly at the interfaces between the transport modes, CAT may lead to new solutions, such as e.g.:

- More efficient operations along the chains of goods transport using loading units that could be transferred from one mode to another, autonomous transhipment operations and specific applications in multimodal chains (i.e. the example of the Automated Systems for the last/first mile between rail terminals and warehouses in multimodal hubs/logistics clusters)
- Seamless passenger travel experiences
- Mergers between rail and road in „virtual tracks", air and water in drone concepts, rail and air in hyperloop
- Cross-modal ride, vehicle and infrastructure sharing
- Comprehensive gains of efficiency of space, energy and resources
- Spill-over effects from other sectors such as health, energy, or robotics

Proposed Innovation Support Measures

While an inconsiderate mixing of CAT-related innovation support measures should be avoided as it would be of limited effect, the cross-modal links, transfer potentials and new opportunities could well be a matter of programming and partnership activities of the European Commission, the Member States and the industrial sectors, e.g.:

- Funding R&I on automation of operations along travel and goods transport chains/at interfaces across modes, e.g. in stations, ports, hubs

- Facilitation of CAT technology transfer across disciplines and between modes, see table

- Establishing platforms for the sharing of best practices on common issues, e.g. connecti-vity, cyber security, AI, universal design

- Exploitation of concept transfer e.g. for harmonization, standardization and legislation (sandboxes)

- Development of comprehensive concepts (e.g. city robotics, traffic management)

- Feasibility studies for cross-modal CAT solutions such as hyperloop or others

- Participation of citizens in the co-creation of new CAT related mobility solutions

- Comprehensive study of impacts on environment and climate enabling sustainable choices

- Coordination with programs on enabling digital technologies such as the Electronic Components and Systems for European Leadership (ECSEL) Joint Undertaking and its Lighthouse Mobility.

- Coordination with the other STRIA roadmap topics such as smart mobility or electrification.

| Glossary | |
|---|---|
| ADAS | Advanced Driver Assistance Systems |
| ADS | Automated Driving Systems |
| AI | Artificial Intelligence |
| ATO | Automatic Train Operation |
| AIS | Automatic Identification System |
| AV | Automated Vehicle |
| B2A | Business to Administration |
| B2B | Business to Business |
| BRT | Bus Rapid Transport |
| C-ITS | Cooperative Intelligent Transport Systems |
| CAD | Connected Automated Driving |
| CART | Connected Automated Rail Transport |
| CARTRE | Coordination of Automated Road Transport Deployment for Europe |
| CAT | Connected Automated Transport |
| CAV | Connected Automated Vehicles |
| CBTC | Communication Based Train Control |
| CCNR | Central Commission for the Navigation of the Rhine |
| CEF | Connecting Europe Facility |
| DDT | Dynamic Driving Task |
| DI | Digital Infrastructure |
| DP | Dynamic Positioning |
| EPoSS | European Technology Platform on Smart Systems Integration |
| ERRAC | European Rail Research Advisory Council |
| ERTRAC | European Road Transport Research Advisory Council |

| | |
|---|---|
| ESO | European Standardization Organizations |
| ERTMS | European Railway Traffic Management System |
| ETCS | European Train Control System |
| GoA | Grade of Automation |
| FOT | Field Operational Test |
| GHG | Greenhouse Gas |
| GSM | Global System for Mobile Communications |
| HMI | Human Machine Interface |
| ICT | Information and Communication Technologies |
| IMO | International Maritime Organisation |
| IoT | Internet of Things |
| ISAD | Infrastructure Support for Automated Driving |
| IT | Information Technology |
| ITS | Intelligent Transport Systems |
| IWT | Inland Waterway Transport |
| KPI | Key Performance Indicator |
| MaaS | Mobility as a Service |
| MASS | Maritime Autonomous Surface Ships |
| MSC | Maritime Safety Committee |
| MUNIN | Maritime Unmanned Navigation through Intelligence in Networks |
| NFAS | Norwegian Forum for Autonomous Ships |
| ODD | Operational Design Domain |
| OEDR | Object and Event Detection and Response |
| OEM | Original Equipment Manufacturer |
| R&I | Research and Innovation |

| | |
|---|---|
| RIS | River Information Services |
| SAE | Society of Automotive Engineers |
| SIL | Safety Integrity Level |
| SCOUT | Safe and Connected Automation of Road Transport |
| STM | Sea Traffic Management |
| STRIA | Strategic Transport Research and Innovation Agenda |
| ToC | Transition of Control |
| TRIMIS | Transport Research and Innovation Monitoring and Information System |
| V2V | Vehicle to Vehicle |
| V2X | Vehicle to X |
| VTS | Vessel Traffic Service |

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Connected and automated transport (CAT) is an important area of digital technology that promises a number of benefits for the individual, the society and the economy in the various sectors of transportation. In general, CAT can support the competitiveness of the European transport manufacturing, telecom and IT industries on worldwide markets, and enable potentially disruptive innovation, which may lead to services concerning the transportation of both people and freight. These possibilities benefit all transport modes, therefore, connected and automated road, rail, waterborne and air transport are high on the agenda of the European Commission and the public authorities of the EU Member States in their planning for interoperable and multimodal mobility and transportation systems of the future.

*Studies and reports*