

STRIA Roadmap

CONNECTED AND AUTOMATED TRANSPORT (CAT)

Date: 09.11.2016
Version: VII

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0. Executive Summary

This Strategic Transport Research and Innovation Agenda (STRIA) roadmap document addresses the Research and Innovation (R&I) activities and other policy support measures required so that the concepts of connected and automated¹ transport (CAT), for all transport modes, may contribute to the Energy Union 2050 goals in the domains of decarbonisation, greater efficiency and competitiveness.

Connectivity and automation in transport (CAT), covering all modes, provides opportunities for a variety of policy targets and objectives. CAT technologies can largely contribute to increase the efficiency and safety of the transport system. CAT will also be a necessary factor in establishing other technical solutions in the transport system, such as electro-mobility, new vehicle designs, new infrastructure, network traffic management and smart transport and mobility in general.

In all transport modes connectivity and automation could deliver significant benefits in terms of fuel savings; 8-13% for trucks (platooning)² and up to 25% through automation of existing vessels and more efficient vessel operation³. By emerging innovative mobility concepts, as enabled through connectivity and automation, even larger contributions to fuel and emission reduction can be expected, e.g. through modal shift to greener modes and higher vehicle occupancy rates for passengers or optimisation of the logistics and the supply chain system. It is estimated that using CAT technologies for tracking and planning of goods and making goods hubs more efficient (thus leading to a better filling grade of heavy goods vehicles) can lead to a fuel and emission reduction in the range of 50-60%. Additional benefits of CAT technologies include improved traffic flows (congestion costs EU around 1% of its GDP/year)⁴.

CAT in its ultimate form, as fully unmanned and automated vehicles, will also enable completely new transport systems to be realised. Unmanned systems will reduce energy consumption in themselves by removing all energy uses associated with the personnel on-board as well as by providing more space for cargo in a given vehicle size. Completely new transport systems can be developed to favour the use of electric or fuel-cell powered vehicles. CAT can also be used to design more flexible systems that make it more cost-effective to use the most energy-efficient mode of transport, e.g. rail or waterways. It will be a crucial factor in tomorrow's transport system.

As technology and innovation advance and systems are implemented and tested on a wider scale, new and very different solutions for freight and passenger transport may emerge. This potentially long transition process from the current situation needs to be actively managed by policy makers, as negative outcomes are also possible. For example, the very likely network-wide capacity gains could lead to induced traffic, and therefore increase the number of vehicles on the road. In addition, attraction to CAT might lead to an undesirable modal shift, e.g. for freight from rail to road.

CAT is furthermore critical if the European transport-related industry is to preserve and consolidate its global competitiveness. In particular, vehicle manufacturers are competing in a worldwide race toward vehicle automation and connectivity with newer entrants e.g. from the IT sector. CAT includes potentially disruptive technologies that provide great opportunities for the European industry and new research led start-ups to create new markets, also internationally. The emergence of innovative mobility services,

¹ “Automated” vehicles or vessels include some form of safety-critical control functions (such as steering, acceleration or braking) and operate without direct driver input. “Connected” vehicles or vessels can exchange information wirelessly with the vehicle/vessel manufacturer, third-party service providers, users, infrastructure operators and/or other vehicles.

² SARTRE project: ‘D.4.3 Report on Fuel Consumption’, Applus+IDIADA, 2014

³ Pathway to low carbon shipping. Abatement potential towards 2030. DNV report, 2009.

⁴ Transport White Paper IA (http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm).

enabled by CAT technologies, has the potential to provide more inclusive mobility, and can give better access to jobs and training, which will benefit the economy.

CAT is expected to improve safety in all transport modes. Human error is a major cause of accidents in all modes and increased and correct use of CAT will substantially reduce these accidents. Removing the human element from vehicle operation can have large benefits, by lowering accident rates and severity, particularly when automation is linked to deep-learning of the system. Other positive impacts on safety can be expected from improved technical monitoring and fewer technical faults. Integrated with more traffic monitoring and better management, CAT has the potential to substantially reduce the numbers of lives lost and injuries. Theoretically, one could see as much as a 90% reduction in accidents for some modes.

The *key output* of this STRIA roadmap is the *strategic implementation plan*, where specific *research and innovation actions* and other policy support for a full deployment of CAT technologies are proposed. Due to the very specific properties of each transport mode the report outlines mode specific key recommendations as well as cross modal issues. The respective action plans discuss R&I topics such as:

- Technologies, in particular regarding sensors, detection and perception. Safety considerations.
- Optimised use of ICT Technologies (Internet of things, Big Data, Visualisation, Cloud Computing, etc.). Artificial Intelligence.
- Knowledge about the human's understanding, use and acceptance of CAT systems.
- Drones, unmanned vehicles and vessels, and associated infrastructure, management systems.
- Intelligent systems for freight, new vehicle concepts beyond current mode definition.
- Demonstration projects, large scale test facilities, testing procedures, evaluation methodologies.
- Operations, traffic management.
- Infrastructure – identification of essential changes.
- Support for cities, urban and interurban environments for deployment, including handling of "the transition phase" and mixed situations.
- New business models, competitive CAT systems (mass)production, benefit assessment of CAT.

Considerations cutting across the individual modes are e.g. the maturity level of technologies, public and user acceptance, business cases, cyber security, privacy and liability, as well as risks related to a wider introduction of new solutions. Other concerns include policy support and guidance, legal and regulatory framework, standards and training and education regulatory framework.

1. Introduction

1.1 Background and Objectives

This STRIA roadmap document addresses the necessary Research and Innovation (R&I) activities and other policy support measures for all transport modes relating to connected and automated transport (CAT) with the main objective of contributing to the Energy Union goals in the domains of decarbonisation, greater efficiency and competitiveness. On 25 February 2015, the European Commission published the Communication “A framework Strategy for a Resilient Energy Union with a Forward-Looking Climate change Policy”⁵. The Communication describes the framework to achieve the 2030 EU climate and energy goals on the basis of five closely interrelated pillars.

The pillar on research, innovation and competitiveness highlights the central role that Research & Innovation (R&I) needs to play in attaining these goals while fostering competitiveness and the need to establish an integrated EU R&I strategy encompassing several sectors. It is in this framework that the European Commission is developing the Energy Union Integrated Research, Innovation and Competitiveness Strategy (EURICS). Transport is one of the sectors that hold the greatest potential for contributing to the Energy Union goals in the domains of decarbonisation, greater efficiency and competitiveness. In order to realise this, several technical, financial and socio-economic hurdles need to be overcome.

To this end, the European Commission initiated the Strategic Transport Research and Innovation Agenda (STRIA) which focusses on the development and deployment of low-carbon transport technology solutions encompassing at the same time digitalisation, safety, security and other relevant aspects. The STRIA is conceived as one of the core elements of EURICS and a major contributor toward the achievement of the Energy Union goals. The STRIA builds on seven thematic areas, which have been selected on the basis of their potential impact on the transformation of the EU transport system. These areas are:

- Electromobility;
- Alternative fuels;
- Vehicle design & manufacturing;
- Connected and automated transport (CAT);
- Transport infrastructure;
- Network traffic management systems;
- Smart transport and mobility services.

For each thematic area, a roadmap has been developed with the aim of outlining the steps needed to support and speed up the research, innovation and deployment process of innovative technologies.

Addressing the subject of CAT, this roadmap reviews the current state of the art and identifies major challenges, opportunities and policy options to support and speed up the research, innovation and deployment process leading to a wide market uptake of connectivity and automation technologies in transport (including road, rail, air and waterborne). The primary objective of this roadmap is to provide a direction for the priorities for R&I for CAT between now and the year 2050. This roadmap should be viewed in conjunction with the other complementary roadmaps in this series.

⁵ COM(2015) 80 final: <https://ec.europa.eu/energy/en/publications/energy-union-package>

Increased connectivity and automation are principal trends that will have significant impact on how users, businesses and society will perceive and experience mobility in the future. Many benefits are expected from the increased use of connectivity and automation technologies in all modes of transport - at individual and at social level - and they are instrumental for the cross-modal integration of transport. Increasing safety is often seen as the main driver for deploying CAT, because removing the human element from vehicle operation can have large effects on lowering collision rates and severity.

Another main driver for accelerated introduction of CAT is competitiveness. CAT is critical for the ability of the European transport related industry to preserve and consolidate its global competitiveness. In particular, vehicle manufacturers are competing in a worldwide race toward vehicle automation and connectivity with newer entrants e.g. from the IT sector. CAT can also contribute to the Energy Union targets for GHG emissions and energy efficiency, and to primary transportation policy objectives, as well as productivity, e.g. efficiency of traffic flows and improved infrastructure capacity. There are also high expectations regarding economic growth, for instance due to dramatic reductions in the numbers of deaths and injuries from road-traffic collisions.

1.2 Approach and Structure of the Report

This STRIA roadmap identifies the major challenges, barriers, R&I priorities and policy options to support and speed up the deployment process leading to a wide market uptake of connectivity and automation technologies in transport (road, rail, air, and waterborne). Breakthrough R&I activities with high implications for increased safety, contributions to climate and energy objectives, and improved competitiveness of European industry are addressed. Non-technical challenges relating to legislation/regulatory aspects, public uptake and acceptance, infrastructure, testing conditions and other socio-economic issues are also considered. The roadmap proposes actions to be implemented in the short- (up to 2020), medium- (up to 2030) and long (up to 2050) terms.

Due to the specific properties of each transport mode, the development of the CAT roadmap has initially been done for each mode. Commonalities have then been extracted and systemized and are presented in the main sections. Transportation and mobility of persons and goods have been considered for the four existing modes road, rail, air and waterborne transport. However, the emergence of completely new concepts and vehicles within each or across modes, for example, fully automated vehicles without conventional steering wheels and pedals have also been considered.

The starting point of this roadmap is to review the key transport policy targets in terms of decarbonisation, growth, competitiveness and safety, and to analyse the potentials of CAT to contribute to these policy targets. The "Baseline and state-of-the-art analysis" provides an overview of the current status of the development of CAT technologies, policy documents and barriers to implementation for all transport modes. The chapter on the state-of-the-art analysis helps to identify specific research gaps and deployment barriers and to define those actions that will be needed to achieve the above-mentioned policy targets. The chapter "Strategic Implementation Plan" presents the main strategic priorities to support the deployment of CAT technologies and proposes a number of R&I actions and other policy support options to be implemented in the short, medium and long terms. Many proposed actions are mode-specific, but others are of horizontal and/or cross-modal nature.

1.3 Methodology for Roadmap Development

The CAT roadmap has been prepared in a very short time period, and draws on the current knowledge and experience of experts in the field of CAT. The roadmap development is led by a core team of 6 co-rapporteurs, with expertise on CAT technologies in the various transport modes. The core team started their work in April 2016 and prepared a first version of the document, based on a limited literature review. This version was discussed at a consultation workshop on 27 May 2016 in Brussels and modified according to input received at the workshop and as follow-on written feedback.

A general STRIA consultation workshop for all seven technology areas were held in Brussels at 23 June 2016. This also provided input to the document. Another CAT workshop was held in Brussels 7 September 2016. In the weeks after the workshop there were more opportunities for stakeholders and experts to give valuable input and feedback to define future transport R&I policy options. The main objectives of the September consultation workshop was to validate the content of the draft roadmap on “CAT”, identify important gaps and discuss further recommendations for R&I actions and policy options to support the wider market uptake of connected and automated transport technologies. Many expert contributions have been considered in the preparation of this version of the roadmap. Because of the very tight time constraints, the roadmap has been prepared in isolation from the other STRIA roadmaps, which have been prepared in parallel. The author team considers that a further iteration of these roadmaps would be appropriate when all seven roadmap documents have been submitted to the Commission.

2. Contribution to Policy Targets and Objectives

Connectivity and automation in transport (CAT), covering all modes of transport, provides opportunities for contributing to a variety of policy targets and objectives. As technology and innovation advance and systems are implemented and tested on a wider scale, new and very different solutions for freight and passenger transport may emerge. This, potentially long transition process from the current situation, needs to be actively managed by policy makers, as negative outcomes are also possible.

To show some examples of this, in the road sector these dangers are already becoming visible and are being discussed by the community. For example, the very likely network-wide capacity gains could lead to induced traffic, and therefore increasing the number of vehicles on the road. In addition, attraction to these technologies might lead to an undesirable modal shift, e.g. for freight from rail to road, for passengers from walking or cycling to road-based systems and for drivers from rail to their own vehicle.

Specific contributions to policy targets and objectives are described below, in relation to the Energy Union and the concept of decarbonisation, growth and competitiveness of the EU, and safety and other related issues. Common issues across all modes are identified in addition to particular modal considerations, as well as points on inter-modality and cross-modality, and the likely emergence of alternative modes (in addition to current modes) and services.

It is important to point out that some (often limited) direct benefits can be expected from CAT in all of the above categories, but additional and likely much larger gains are to be expected from a paradigm shift in transport (freight and passenger) service delivery, which is enabled by the emergence of the CAT technologies. These impacts are much more difficult to estimate, as they rely heavily on specific characteristics of the emerging concepts and their interplay with other innovative systems, as well as those continuing legacy systems. The text highlighted in the box on the next page shows some characteristics of how the transport system might evolve up to 2050, due to new developments of CAT technologies. The description of these characteristics must inevitably be vague, as there are many uncertain factors related to the development of CAT technologies.

Relevant Mega-Trends and Scenarios

There are numerous studies and articles aiming at predicting the future of our transport system, and several also address the topic of CAT.

Of all *megatrends* the following have been considered to be of particular relevance for CAT:

- **Climate change concerns**, leading to a drive towards decarbonisation
- **Urbanisation**, leading to new urban planning needs and urban sprawl
- **Increasing inefficiency of road transport system (congestion, demand for parking space, etc.)**
- **Demographic changes** including aging population, migration
- **Ever-increasing connectivity of persons and "things"** (Internet of Things).
- **Industrial development**, e.g. disruptors entering the market, globalisation of markets

Some *characteristics* of how the transport system may evolve up to 2030-2050 include:

- **Autonomous and connected** vehicles/vessels/actors (transport users) almost everywhere.
- **Connectivity:** Movement of persons and of "things" (goods) will become the focal points of the transport system. All people will be connected to the transport system, as will be all goods (via the "Internet of Things"), and they will collect and share information. There will be possibilities for "opting out" in which case automation will be able to step in with degraded services and make sure that the desired mobility takes place in a safe, efficient way.
- **Mobility:** Mobility will become a service. Mobility options between points "A" and "B" will be optimised based on individual multi-criteria choices and personal preferences (refers to persons, businesses and goods). Options will include "no transport at all" enabled by digitalisation (e.g. 3D printing, e-material, virtual meetings). Transport will continue to have two dimensions: "must"/ "utility"/ required, and "want"/ pleasure/ desire.
- **Highly efficient** regional, long-distance passenger and freight transport
- **Cross-modal solutions** and the associated infrastructure will allow for efficient and flexible service options for persons and goods. The utilisation of assets will also be improved. Increased efficiency of the transport infrastructure will become an important contributor to reducing the CO₂-emissions.
- **Transport infrastructures:** will be more critical than ever for leveraging automation and connectivity. This includes also digital infrastructure as well as automated maintenance and repair functions, to a large extent thanks to CAT.
- **Resilience:** Changes and unforeseen extreme events – natural or manmade – and their effect will be able to be handled by the transport system. Obvious examples are weather, and attacks. The CAT system will have the ability to withstand, recover and rebound. When a building block of the system becomes outdated it will be able to be easily replaced by an upgraded part.
- **Adequate levels of privacy, security, data protection and usage**

Scenarios allowing the transition towards full deployment of CAT technologies include:

- **Mobility as a Service; any time, any place - i.e. use it, don't own it**
- **Fully automated private luxury**
- **Multimodal and shared automation**
- **Letting go on highways⁶**

⁶ Driver at the wheel? Self-driving vehicles and the traffic and transport system of the future. KiM, the Netherlands, October 2015

2.1 Energy Union and Decarbonisation

Whilst efficient and inclusive transport is the backbone both of the economy and society as a whole, its use of fossil fuels and inherent inefficiencies pose a challenge in terms of emissions and energy usage.

Contributions to the Energy Union goals and to the decarbonisation of transport can be achieved by using CAT technologies in all transport modes, in particular by:

- **Removing the human element from vehicle operation.** This can achieve the **optimum performance** parameters (e.g. speed, acceleration, jerk, etc.) of individual vehicles of all modes and, particularly through the connectivity element, of the whole modal or multi-modal system.
- **Minimising the headways** or spacing between vehicles through implementing moving block principles and automated control and connectivity (i.e. not needing minimum safety distances based on human error and reaction times), will free up space and **increase capacity** of links or networks.
- Through emerging **innovative mobility** concepts, as enabled through CAT technologies, even larger contributions can be expected, e.g. through **modal shift** to a greener mode and **higher vehicle occupancy rates** for passengers, less need for car-ownership through **mobility as a service** or more **efficient vehicle utilisation** for freight transport.

Other more **mode-specific** and more quantitative **contributions to the Energy Union and the decarbonisation** of transport include the following:

Road Transport

- According to the recent ERTRAC roadmap⁷, the main policy objectives relating directly or indirectly to the Energy Union, where higher levels of automated driving can contribute are:
 - safety (reduce accidents caused by human errors)
 - efficiency and environmental objectives (increase transport system efficiency and reduce time in congested traffic, smoother traffic will help decrease energy consumption and vehicle emissions)
 - comfort (enable users' freedom for other activities when automated systems are active),
 - social inclusion (ensure mobility for all, including elderly and impaired users), and
 - accessibility (facilitate access to city centres).
- Broad-ranging e-mobility market ramp-up through close networking with infrastructure and optimisation of changing behaviour enabled by connectivity, and long-term energy savings on the roads, with a corresponding reduction in emissions through road/ traffic-adjusted (adaptive) operating strategies (e.g. engine control).
- Recent studies⁸ by ERTICO⁸ and ACEA⁹ indicate two important possible benefits of CAT, related to the Energy Union agreements:

⁷ ERTRAC Automated Driving Roadmap, V5.0, 21/07/2015, http://www.ertrac.org/uploads/documentsearch/id38/ERTRAC_Automated-Driving-2015.pdf

⁸ Study of Intelligent Transport Systems for reducing CO₂ emissions for passenger cars, ERTICO supported by ACEA, Jean-Charles Pandazis and Andrew Winder, September 2015

⁹ Joining Forces to tackle the road transport CO₂ Challenge, a multi-stakeholder initiative, ACEA, 2016

- In-vehicle eco-navigation systems (dynamic navigation tools using real-time data to reduce fuel consumption, also studied in the eCoMove project¹⁰) have the potential to create a 5-10% reduction in emissions. Eco-driving systems, recognising the driving behaviour and providing the driver with on-trip advice and post-trip feedback, can bring emissions down by 5-20%. Results are highly variable in terms of context: topography, road type, vehicle type and transmission system, HMI, traffic fluidity, etc.
- CO₂ emissions can be reduced by up to another 10% by giving drivers real-time advice on traffic signals and guidance to find a parking space. This reduction only accounts for the vehicles equipped with the system, in those areas where the system infrastructure is deployed (see also the ICT-EMISSIONS project¹¹).

Apart from the effects discussed above, it is not known how user behaviour and transport demand will evolve. Potentially increased availability of affordable door-to-door mobility-on-demand solutions may boost the use of passenger vehicles, eliminating the positive effects indicated. There is no firm empirical evidence for these proposals, although an attempt has been made in a number of publications to provide some indication of possible trends^{12,13}. However, some caveats must be considered because, for example:

- the potential effects of the individual applications cannot be added;
- most studies consider the studied societal or technological changes in isolation.

An example of these effects is discussed in an article by Burghout¹⁴ et al, where simulations showed that replacing commuting traffic in metropolitan Stockholm with automated taxis could be achieved by a fleet of cars at only 8% of normally expected numbers, but traffic volume, and thereby energy consumption, increased by 25%. A general conclusion from the literature indicates that the true energy and emission reduction benefits can only be achieved through shared rides.

A major further effect on fuel and emission reduction can be established if CAT technologies are used e.g. for tracking and planning of goods and making goods hubs more efficient, thus leading to a significant increase in the filling grade of heavy goods vehicles (estimated to be currently in the range of 50-60%). Platooning of vehicles in highways also has the potential to effectively reduce fuel consumption and consequently vehicle associated emissions. Road trains of heavy duty vehicles might achieve up to 15%¹⁵ for a following heavy duty vehicle, averaging a 5%¹⁶ for all the vehicles in the platoon including the leading one in non-ideal scenarios. Platooning also has the potential to increase goods and passenger transport efficiency and be a complementary technology for advanced logistics planning. To unleash the potential of platooning at European level, legislation and regulation must be harmonized accordingly.

Sustainable Urban Mobility Plans (SUMPs) are a major strategic element of the White Paper on Transport 2050 and the related Urban Mobility Package. It is necessary to clarify the interaction between the technological development and especially the urban mobility system – taking the importance of cities into account. Cities need to get more strongly involved in the process of framework setting for CAT.

¹⁰ <http://www.ecomove-project.eu>

¹¹ <http://www.ict-emissions.eu/>

¹² Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles, Zia Wadud, Don MacKenzie, Paul Leiby, Transportation Research Part A, 2016

¹³ An analysis of Possible Energy Impacts of Automated Vehicle, A. Brown, J. Gonder, B. Repac, 2014

¹⁴ Burghout W., Rigole P.J., Andreasson I., Impacts of Shared Autonomous Taxis in a Metropolitan Area, in Proceedings of the Transportation Research Board Annual Meeting 2015

¹⁵ <http://www.sartre-project.eu/>

¹⁶ <http://www.companion-project.eu/>

Rail Transport

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:

- 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 tonne-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 will strive towards carbon-free train operation by 2050 and provide society with a climate neutral transport alternative.

Based on these targets, CAT technologies are seen mainly as enablers of realising the Energy Union challenges of decarbonisation and energy security by:

- Implementation of Internet Protocol (IP) based communication systems to enable fast, safe, reliable and high-capacity connectivity between all parts of the rail system and its environment
- Optimisation of energy consumption through intelligent automation of driving (new algorithms for management of traction/braking), Automatic Train Operation (ATO) and moving block functionalities
- Optimisation of energy acquisition through intelligent and automatic energy management (use of renewable zero-emission sources, wider implementation of solar energy sources, re-use of energy produced by vehicles (e.g. during braking))
- Development of automated systems for controlling energy storage and its usage, also for other modes of transport (e.g. buses)
- Improving efficiency of freight and passenger transport by rail and its interconnectivity with other transport modes, by applying higher levels of automation and intelligent solutions for the last mile, facilitating intermodal exchanges, as well as aiming at faster mobility of goods and persons at lower costs, while improving safety and security ensuring reduced infrastructure needs.

Moreover, stronger legislative measures will be required to introduce the incentives necessary for using environment-friendly modes of transport, supported by CAT technologies.

Therefore, the contribution of rail to transport decarbonisation and in dealing with other mega-trends such as urbanization and demographic change should be supported by well-defined targets for a modal shift to rail, for both passenger and freight, as well measures to support the development of energy-efficient rail technologies.

Air Transport

In 2008 the global stakeholder associations of the aviation industry (Airports Council International, Civil Air Navigation Organisation, International Air Transport Association and International Coordinating Council of Aerospace Industries Association), under the umbrella of the Air Transport Action Group, committed to addressing the global challenge of Climate change and adopted a set of ambitious targets to mitigate CO₂ emissions from air transport

These include the following:

- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020
- A cap on net aviation CO₂ emissions from 2020 (carbon-neutral growth)
- A reduction in net aviation CO₂ emissions of 50% by 2050, relative to 2005 levels

Additional European objectives according to Flightpath 2050¹⁷ include the following:

- In 2050 technologies and procedures available will allow a 75% reduction in CO₂ per passenger kilometre (relative to the capabilities of a new aircraft in 2000) and taxiing will be emission free.

The two significant EU R&I programmes for aviation, Clean Sky and SESAR, have also set up some specific targets in terms of decarbonisation:

- **Clean Sky** with a 50% reduction of CO₂ emissions through vehicle operational and technical improvements together with a green product life cycle: design, manufacturing, maintenance and disposal / recycling.
- **SESAR** with an environmental performance ambition to reduce CO₂ emissions by up to 10% compared to the 2012 level. Furthermore, the SESAR vision builds on the notion of trajectory-based operations and relies on high levels of automated support at every stage of the flight.

Moreover the Airport Carbon Accreditation Programme was launched by the Airports Council International Europe in 2009 and has now expanded globally. Four levels of certification exist (from mapping to neutrality). The objective is to enable as many airport as possible to best manage their CO₂ emissions.

The ACARE targets in particular are very ambitious, especially since the aviation sector is experiencing a significant change in terms of air vehicles which can be grouped under two categories: conventional air transport and the new entrants. Due to the significant difference in terms of operation and CAT development of the two categories, this split calls for two different approaches to decarbonising the aviation sector through its reliance on CAT.

The first approach concerns the conventional business activity linked to manned passenger and freight aviation that will directly contribute to the in-sector decarbonisation targets given above. This decarbonisation is currently being addressed through improvement steps (evolutionary approach) including and making use of increased levels of automation for the air vehicle (Clean Sky programme), fuel optimisation in all phases of flight - acting both on flight profiles and optimal routing and traffic pattern efficiency (SESAR programme) – and airports in an increasing virtualised environment. Multimodality is seen as an opportunity to deliver new efficiency improvements to the overall transport system and therefore further contribute to the decarbonisation of the sector. Current zero-carbon taxiing solutions are not fully satisfactory as they bring other issues in terms of operation or business models. R&I actions in this area could deliver additional environmental benefits.

However a second approach needs to be developed to embrace the revolution taking place from new airspace users, notably the unmanned air vehicles which operate in an extended airspace from very low levels to very high levels (drones, space aircraft, balloons, etc.). For this category of air vehicles, a radical change in the approach to decarbonisation of the sector is needed. It is essential to take into account their specificities and the intrinsic benefits they can potentially deliver. In particular, drones are by definition

¹⁷ Flightpath 2050: Europe's Vision for Aviation - Report of the High Level Group on Aviation Research, European Commission, DG Research and Innovation, DG Mobility and Transport, 2011

developed with high level of automation and connectivity. Additionally, the number of such air vehicles is expected to far exceed the number of conventional aircraft in the near future. Finally, they have the potential both to contribute to totally new businesses and to transfer activities from other industrial sectors, including other transport modes, to the aviation sector. Although new business opportunities are just emerging and most of them are limited in payload, by 2050, passenger drones could bring a real revolution to the toolbox of transport mobility solutions for achieving the 4 hour door-to-door goal. Freight solutions are currently being successfully tested, notably to fill the last mile journey gap, contributing to a more integrated and efficient transport system. However, their integration into conventional air traffic management creates safety, efficiency and capacity issues that will impact the CO₂ emissions of the overall system.

To maximise the decarbonisation of the aviation sector and indeed meet the challenging 2050 goals set by ACARE, it is crucial and urgent to ensure that appropriate measures are taken (from research to policy) to ensure that the development of the airspace user, notably the new entrants, does not negatively affect the decarbonisation efforts of the conventional aviation sector, and in particular that any impact on decarbonisation they have is accounted for appropriately. It is as important to continue beyond the existing aviation research programmes to search for new solutions which could accelerate the decarbonisation of the conventional air transport segment, from and beyond cross modal solutions.

Another barrier to achieving aviation's environmental goal is climate change. The severity of weather impacts is becoming one of the key barriers to aviation network resilience, potentially creating severe ATM disruptions that will result in a significant increase in CO₂ emissions compared with optimised 4D trajectories. By enabling better weather information, predictions, and flight plan reconfigurations, CAT is instrumental in increasing network resilience and in reducing aviation emissions. Further reliance on CAT to combat the effect of climate change through reducing CO₂ emissions is becoming increasingly important.

Finally, to optimise air transport CO₂ reduction, CAT solutions must be supported by the appropriate regulatory framework which would impose to flying the lowest CO₂-emission trajectory.

The exact impact of CAT on CO₂ emissions is difficult to assess, as it is an enabling technology with many applications across different domains, stakeholders and technologies. 20% of CO₂ reduction seems to be a conservative value, since CAT is enabling a large part of the air transport innovations. This value considers a contribution of 15% from the European technical/operational (ATM, Airport and aircraft) aspects and 5% for the political.

Waterborne Transport

The Transport White Paper¹⁸ cites the following decarbonisation objectives that are relevant for waterborne transport:

- Thirty per cent 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 by using more energy efficient transport modes. Autonomous waterborne vessels may enable completely new transport solutions that can achieve this objective for freight moved over even shorter distances. For example, small autonomous coastal vessels, canal and urban waterway vessels may be competitive with road transport on distances shorter than 300 km. Automation will facilitate more seamless integration between modes.

¹⁸ White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Brussels, 28.3.2011. COM (2011) 144 final.

- Reduce EU CO₂ emissions from maritime fuels by 40 % (50 % if feasible) by 2050.
- Ensure that all core seaports are sufficiently connected to the rail freight and, where possible, inland waterway system. This is important to enable cost-effective transshipments to and from waterborne transport and will be a major factor in achieving transfer of cargo from road to rail and waterways.
- Achieve essentially CO₂-free city logistics in major urban centres by 2030. Waterborne craft may contribute through electrical ferries, waterbuses and freight vessels that are now starting to be deployed.

A communication from the Commission on the EU maritime transport policy¹⁹ also identifies various goals and objectives for waterborne transport. Many of these are general, but some are directly relevant for CAT and the decarbonisation of transport:

- Increased use of inland waterways have a large potential to reduce road congestion and to reduce emissions. For example, a large Rhine barge may carry almost 1,000 freight containers, and compared to trucks, inland waterway transport is much more energy efficient, safe, almost congestion-free and silent. Inland waterways span 20 member states with a network of around 37 000 km. However, the sector suffers from an aging fleet, relatively low innovation levels²⁰ and low water levels partly caused by inadequate infrastructure. CAT can be an important contributor to achieving more efficient services that have better interconnectivity with the wider transport network. Furthermore, the regulatory environment for advanced CAT solutions on inland waterways is simpler than for international shipping.
- A reference framework should be established to enable the deployment of ‘e-Maritime’ services at European and global levels. Such e-services should also encompass public administrations, port communities and shipping companies. This is directly related to the discussion of the CAT role in the STRIA thematic areas. This will support improved logistics connectivity, improved sea traffic management and improved automation of waterborne transport operations.

In general, there is a significant energy savings potential in the waterborne sector by creating better transport systems and renewing the fleet, but the greatest potential may be in promoting modal shift from road to more carbon efficient transport modes such as inland waterways, coastal short sea shipping and rail. CAT can be a major contributor in all areas, by improving interconnectivity between modes and ports to make the transport system and vessels more efficient and reliable.

Policy documents are mostly identifying high-level objectives without suggesting specific CAT measures to reach them. However, it is expected that the following main CAT developments in the waterborne sector will be the strongest contributors to decarbonisation.

- **Ship Automation:** The main potential for energy reduction by automation is in improved voyage execution and in better control of the energy consumers. The latter also includes better monitoring of the technical condition of these systems. The savings are estimated to be about 5 to 20% of the

¹⁹ Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of the Regions: Strategic goals and recommendations for the EU’s maritime transport policy until 2018. COM (2009) 8.

²⁰ Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and The Committee Of The Regions: Towards quality inland waterway transport - NAIADES II. SWD(2013) 324.

energy consumption today²¹. Increased automation will also increase competitiveness for short sea and inland waterway vessels, which is necessary to encourage transfer of freight transport from road to ship

- **Ship Autonomy:** Additional energy savings from fully unmanned ships is most obviously by removing energy consumption from the accommodation section, related life support systems and personnel safety systems. Having no crew on board also enables structural improvements of the ship, e.g. reduced wind drag in smaller superstructure as well as increased optimization of ship speeds and heading as crew welfare need not be taken into account. Energy savings can be about 5 to 30% of today's consumption for the same speed and cargo volume, dependent on ship size and type²². Autonomous and unmanned ships will also enable new types of coastal shipping with electrified vessels. This enables a paradigm shift in the last mile transport of freight from ports around Europe's coastline. Freight could be fed directly into smaller ports with automated loading and unloading facilities. Since 40% of the EU population live within a coastal region such new systems could achieve a massive impact.
- **Traffic Management:** Just-in-time arrival and optimal speed during passage may reduce energy consumption from 10% to 50% for otherwise well managed voyages^{21,23}.
- **Integrated logistics system:** This can be used to optimise the use of different transport modalities as well as for optimization within each mode. This can significantly reduce total emissions. No concrete figures for potential savings in the waterborne sector are available, but the SELIS²⁴ project has an overall goal of 30% reduction of GHG emissions through improved integration of logistics systems.
- **Digital Connectivity** is a key facilitator that underpins the above. Secure and reliable connectivity at sea is still a technological challenge.
- **Physical Connectivity:** To maximise the benefit from increased automated of shipping and inland waterways, it is necessary to increase investments in physical port infrastructure and intermodal terminals and hubs, e.g. in automated mooring, port services hook-up, robotic cargo handling, intermodal connections etc.

²¹ Pathways to low carbon shipping Abatement potential towards 2030. DNV report 15 December 2009.

²² MUNIN Deliverable 9.3: Quantitative assessment, V1.0, 2015-10-12 (available from www.unmanned-ship.org).

²³ Project presentation – SynchroPort, Magnus S. Eide, Tore Longva, DNV R&I, at www.fargisinfo.com.

²⁴ Horizon 2020 research project started 1st September 2016: <http://www.selisproject.eu/>

2.2 *Growth and Competitiveness*

Efficient transport is crucial for *economic growth* and, indirectly, *job creation*. Transport is also global, so effective action requires strong *international cooperation*. With the advent of the *sharing economy and disruptive technologies* in the transport sector, new challenges have emerged for traditional industries. Thus, CAT is one context within which EU *businesses need to reposition* themselves in order to be able to compete successfully at a global level. Competitiveness issues here include both the performance of the EU transport industry in relation to other countries or regions, as well as competition amongst transport modes to e.g. to lead to modal shift towards greener modes. Here, also, competition between modes and modal-shift effects are included.

The implementation of CAT technologies in all transport modes can contribute to more *growth and competitiveness* of the EU, in particular through the following:

- The *emergence of innovative mobility services* has the potential to provide *more inclusive mobility*, giving better *access to jobs and training*, which in return will benefit the economy.
- Wide implementation of CAT will enable Europe to have a *more efficient system of transport operation*, especially if all modes are included. This will have a direct positive effect especially on the *European logistics industry* but e.g. also on public transport.
- Some parts of the suggested CAT technology, e.g. autonomy, are potentially disruptive technologies that provide great opportunities for European industry to create new markets, domestic and international.
- CAT provides an opportunity for *existing industry* as well as *research-led start-ups* to position the *EU amongst the world leaders* in these technologies.
- Improved transport services will also help other industries and the society at large. They provide more timely, more reliable and in some cases faster transport services to the production industry, consumers and society.

Other *more mode-specific contributions to growth and competitiveness* of the EU include the following:

Road Transport

- Opportunity of building on the legacy of the European vehicle industry:
 - Some 12 million people are employed in the European automotive industry
 - European automotive suppliers directly employ 5 million people
 - European automotive suppliers invest €18bn in RDI per year. They are the biggest private investor into research and innovation
 - 18 million vehicles are manufactured in Europe each year, contributing to the stability and growth of the European economy

Rail Transport

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 triples 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 the modes. The level playing field between the various modes should be better monitored by policy measures.

The rapidly growing number of passengers, such as in urban and suburban rail services, with yearly almost 9 billion passengers for rail and 7,7 billion passengers for LRT and trams annually, shows the importance of rail transport in Europe and the need for proper financing as motivator and enabler of 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 CAT technologies will support strengthening competitiveness of the rail sector in relation to other modes by:

- enabling capacity and performance increase through the deployment of modern train control systems, especially on CEF corridors and in cross-border areas, removing existing bottlenecks
- contributing to maintenance costs reduction for both infrastructure and rolling stock, by introducing better asset monitoring and technologies for modern asset management and maintenance
- Facilitating quick, soft and local innovation instead of organisation long network wide migration of hardware assets, thus supporting progressive harmonisation and higher interoperability of the assets.
- the use of automation in inspection, maintenance and operation

These measures should result in:

- an increase in the availability of the network due to increased reliability and a reduced requirement (in number and duration) for maintenance possessions
- reduction of costs of new build railway infrastructure and rolling stock

The CAT roadmap aims therefore to increase the ability of the European rail supply sector to compete globally. The CAT roadmap supports the Resolution on the competitiveness of the European rail supply industry adopted by the European Parliament Industry Committee in June 2016. 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.

Air Transport

Aviation is a strong driver of economic growth, jobs, trade and mobility for the European Union. It plays a crucial role in the EU economy and reinforces its global leadership position. The EU aviation sector directly employs between 1.4 million and 2 million people and overall supports between 4.8 million and to 5.5 million jobs. The direct contribution of aviation to EU GDP is €110 billion, while the overall impact, including tourism, is as much as €510 billion through the multiplier effect. The availability of direct intercontinental flights is effectively a major determinant in large firm's choices for location of their headquarters in Europe: a 10% increase in the supply of intercontinental flights results in a 4% increase in the number of headquarters of large firms. A 10% increase in departing passengers in a metropolitan region increases local employment in the services sector by 1%.

Over the last 20 years, the EU's liberalisation of the internal market for air services and the substantial growth of demand in air transport within the EU and worldwide, have resulted in the significant development of the European aviation sector. The number and frequency of intra-EU as well as international routes flown, and the number of passengers have increased substantially.

At the same time, growth in air traffic in Europe and worldwide needs to be reconciled with maintaining high standards of aviation safety and security, as well as reducing aviation's environmental footprint and contributing to the fight against climate change²⁵.

Flight path 2050 as the *main driver for the future air transport R&I actions identifies the following goals in terms of competitiveness:*

- The whole European aviation industry will be strongly competitive, delivering the best products and services worldwide and will have more than a 40% share of its global market.
- Europe will have retained leading-edge design, manufacturing and system integration capability and jobs supported by high profile, strategic, flagship projects and programmes which cover the whole innovation process from basic research to full-scale demonstrators.
- Streamlined systems of engineering, design, manufacturing, certification and upgrade processes will have addressed complexity and significantly decreased development costs (including a 50% reduction in the cost of certification). A leading new generation of standards will have been created.

Increased levels of automation up to fully autonomous vehicles and the implementation of virtualisation technologies as well as the use of standardised and interoperable systems are essential to meet European aviation growth and competitiveness goals.

²⁵ "Aviation Strategy for Europe", European Commission, Dec. 7th 2015.

Waterborne Transport

At the start of the 21st century, the maritime transport system is at the forefront of globalisation. In particular, bulk shipments and the move towards "containerisation" has reduced costs and enabled an unprecedented growth of world trade and interconnectivity within the world economy. By volume, 90% of European freight exports and 40% of intra-European freight are seaborne. Maritime transport services also include supporting offshore activities such as oil and gas, renewable energy, undersea services and fisheries. Consequently, an efficient maritime transportation system is essential for Europe's prosperity²⁶. Furthermore, the European maritime transport policy strategy to 2018²⁶ recognizes the importance of the waterborne transport systems as important for general and sustainable growth in Europe:

- European shipping transport services should at least remain as efficient, reliable and sustainable as today. CAT will contribute to this by cutting down on obstacles for loading and discharging cargo and make the operation itself more efficient through automation.
- The shipping industry should at least remain as competitive as today, and have an equally strong or better position in the global markets. Again, CAT will contribute to this with more advanced and integrated waterborne transport concepts that give European maritime industry a competitive edge.

The European waterborne industry, including vessel operations, equipment and yards, is estimated to *directly* contribute around €200 billion to EU GDP and around 650 000 jobs on land and 500 000 at sea^{27,28,29}. With new developments in ocean space and the blue economy, the maritime industry will further strengthen its role in creating new industries and jobs.

Vessels of the Future (VftF) has provided industry targets³⁰ for competitiveness in the maritime sector:

- Increase efficiency of the ship operations and reduce costs with up to 50% by 2050. This will be through reduction in crew costs as well as less technical maintenance and repair. In addition, most reductions in emissions will also reduce fuel consumption, which is a major cost factor in most shipping operations. As for greening of waterborne operations, CAT will play an equivalent role in making the operations more efficient. This is not only through reduced fuel, but also by better utilization of ships and vessels and lower labour costs through automation (see sec. 2.1).
- New shipping concepts brought on by increased autonomy and new ship designs will also open up new markets, both in ship design and operation. This is a high-tech approach to shipping which will be able to give a benefit to European operators. Gains here have not been quantified. This is a direct reference to CAT in the waterborne sector and in particular the potential for automation of port and ship processes as well as the possibility that can lead to new ship and vessel concept with much higher operational efficiency.

Inland waterway transport plays an important role for the transport of goods in Europe. Some 21 out of 28 Member States have inland waterways, 13 of which have an interconnected waterway networks. The potential for increasing the modal share of inland waterway transport is significant³¹. The introduction of CAT in the sector will lead to an increase in competitiveness for the sector. By increasing ship automation

²⁶ The European Union's maritime transport policy for 2018, MEMO/09/16, Brussels, 21. January 2009.

²⁷ Oxford Economics, The Economic Value of the EU Shipping Industry, February 2015.

²⁸ Eurostat Statistical Books, European Business, facts and Figures 2009.

²⁹ Sea Europe: Supplying, Building & Maintaining the Future, 2014 edition. (<http://www.seaeurope.eu>).

³⁰ Vessels for the Future: A Multi-annual Research, Development and Innovation Roadmap for a contractual Private Public Partnership. 2016-04-07.

³¹ http://ec.europa.eu/transport/modes/inland/index_en.htm

there is a large potential for the development of new competitive business models for the smaller, today less used, inland waterways. Furthermore waiting times at locks can be avoided with more automation on ships and on inland waterway infrastructure. Also, the further harmonization of River Information Services (RIS) will support smoother traffic flows and give the inland waterway sector a more competitive role in logistics.

Increased competitiveness and growth in the transport area is highly correlated with the improvements in efficiency that were discussed in section 2.1. The same arguments are equally applicable to competitiveness as to decarbonisation. For the manufacturing industry and with reference to the technical discussions in sections 3 and 4, it is expected that the following CAT development in the waterborne sector is the main contributor to growth and increased competitiveness.

- **Ship Automation and ship autonomy:** As pointed out above, Europe has a very advanced shipping industry and new and more advanced ships and automation systems will clearly strengthen its competitiveness. Some of the technology developments will also be “disruptive” in that they change established business models and this will create new opportunities for Europe’s businesses.
- **Traffic Management, Integrated logistics systems and Digital connectivity:** These areas will also create business opportunities, but probably with a significant lower value than shipbuilding and equipment manufacture. However, these areas are enabling for increased automation and, in particular, ship autonomy and needs to be supported to reach the goals in those areas.

2.3 *Safety and Other Related Issues*

The transport sector as a whole (and the road sector specifically and very visibly) suffers from direct (death and injuries from accidents) and indirect (pollution, noise emission, detrimental effects on urban areas) *negative effects on humans, and society as a whole*. A variety of other *societal issues* that need to be addressed include e.g. *social inclusion* through access to mobility, *community severance* through transport infrastructure, etc.

Contributions to safety and other related issues are made by *all modes* through the implementation of CAT, including the following main element:

- **Removing the human element** from vehicle operation can have large benefits, by *lowering accident rates and severity*, particularly when automation is linked to *deep-learning* of the system (where algorithms are updated based on situations encountered by fleets of vehicles). This is enabled through *connectivity*, data collection and communication with the cloud for analytics and update of the underlying algorithms.

However, *safety concerns* remain, for example, due to *cyber-security* threats in relation to connectivity. There is also considerable work to be done to understand how the “human element” affects safety. For example, there are issues around misuse and abuse of the system and incorrect mental models of system functionality, which are likely to affect perfect system operation. Imperfect technology requires the correct intervention and suitable monitoring by a human operator, which in itself, can lead to new and unforeseen safety problems. The safety impact caused by the gradual introduction of (increasingly) automated vehicles in a mixed environment in which, at least at the beginning, the majority of cars will be manually driven, needs to be assessed and consequently will force industry, policy makers and regulators to dynamically adapt to a continuously evolving scenario.

Other more *mode-specific contributions to safety and other related issues* include the following.

Road Transport

- Vision zero will be a reality with no road-related fatalities or severe injuries. Connected Mobility will make a major contribution to this goal, as emergence of potentially critical situations can be foreseen, leading to longer timeframes for management and improvement of scenarios and therefore early and successful accident avoidance.
- Well designed, user relevant and informative Human Machine Interfaces (HMI) will allow intuitive and seamless transfer of control between the driver and the vehicle. This will leave less room for misuse or misinterpretation of the vehicle information or the traffic situation, thus leading to more appropriate responses by the driver.
- An effective interaction and communication protocol will exist between automated vehicles, the infrastructure and others on the road, especially Vulnerable Road Users
- Technically advanced cameras, lidars³², sensors and radars will allow automation to operate under all environmental and (extreme) weather conditions.
- Effective and safe V2V and V2I communication, resistant to hacking and security attacks will be available and will reduce the safety gap between non-automated and automated vehicles.

Rail Transport

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

- Full supervision modes of ERTMS/ ETCS to ensure that trains will not pass the end of movement authority and that the train speed will be continuously monitored
- Automatic Train Operation to reduce human factor errors by eliminating need for train driver (e.g. advanced technology for obstacle detection)
- CAT 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)

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. In that case warnings could also be extended to other road users.

³² Light Detection and Ranging: Laser based terrain mapping device

Air Transport

The goals relating to *Flightpath 2050 safety and security* include the following:

- Overall, the European Air Transport System will have fewer than one accident per ten million commercial aircraft flights
- Weather and other environmental hazards will be precisely evaluated and the risks properly mitigated.
- Air Transport will operate seamlessly through interoperable and networked systems allowing manned and unmanned air vehicles to operate safely in the same airspace.
- Efficient boarding and security measures will allow seamless security for global travel. Passengers and cargo will pass through security controls without intrusion
- Air vehicles will be resilient to present and future on-board and ground-based security threats, internal and external to the aircraft
- The Air Transport System will have a fully secured, global, high-bandwidth data network, hardened and resilient by design to cyber-attacks

Additional *related Flightpath 2050 goals* include the following:

- Strategic European aerospace test, simulation and development facilities are identified, maintained and further developed.

Automation has proved that it brings significant safety benefits to the air sector (accident rates have been reduced by a factor of ten thanks to increased levels of automation). Higher levels of automation yet, including fully autonomous air vehicles, should further reduce the number of human errors, although new types of safety risk could be introduced. With unmanned aviation, the roles and responsibilities of aviation actors will change significantly. This will require new policy actions in particular to support growth and society's expectations.

Furthermore, increased levels of connectivity, and data processing and sharing will create new cyber-threats. Security, including cybersecurity risks, together with new certification processes which must be more agile to adapt to the dynamic of CAT evolutions **require significant effort in R&I but also call for new R&I frameworks.**

Waterborne Transport

Ships transport huge volumes of cargo with relatively few crew. Thus, safety when considered per tonne-kilometre is undoubtedly high. However, when looked at in terms of accidents to crew, safety is a serious concern. As an example, the fatal accident rate in British merchant shipping from 2003 to 2012 was 16 per 100 000³³ which is 21 times higher than in the general British workforce.

The safety of shipping must also be considered in environmental terms where the possibility of very rare, but highly severe accident remains. All ships carry a significant volume of fuel and many ships carry cargos that can cause serious environmental pollution. As examples, the Prestige oil tanker accident cost approached €10 billion and the Costa Concordia grounding is estimated to incur a cost of around €2 billion.

Larger and larger passenger ships, some sailing in very challenging waters in the Arctic or Antarctic, is also a concern. The Costa Concordia accident caused 32 deaths, but with more than 4200 people on board, the potential for a catastrophe was very high.

In today's shipping industry, the human factor remains the most important underlying cause of marine accidents. In 908 accidents investigated by EMSA in the period 2011 to 2014, 67% were attributed to human errors³⁴. A further 24% were attributed to equipment failure. Efficient application of CAT in the sector, as automation, as decision support or in the form of partly or fully unmanned operation has a great potential to reduce the number of accidents. Application of CAT will aid the operator and remove many accidents in the human factor category. It will also improve monitoring of technical systems and can give early warning of equipment defects before it fails completely.

Vessels for the Future³⁰ has proposed the following targets for the future safety of shipping:

- By tackling risks, the safety of ship crew should be increased at least by a factor 10 so that fatalities and injuries would be comparable to similar land industry.
- Passenger safety is also a priority, to address risks to reduce fatalities in case of accidents and also to maintain confidence in waterborne transport.

The communication from the commission on the maritime transport policy¹⁹ also identifies various other goals and objectives for waterborne transport. Many of these are general, but some are also directly relevant for CAT:

- Ship transport of oil, LNG and other energy carriers is critical to Europe's energy security. 90% of oil is transported by ship, LNG transport is increasing and other energy carriers are also often transported by ship. Thus, European controlled shipping is strategically very important in times of increasing unrest and uncertainty in the world³⁵. Shipping's crucial strategic role for Europe and the world will not decrease in the near future. CAT will contribute to maintain a competitive shipping industry in Europe as well as improve security in the transport systems themselves. This is achieved through better data integration and improved monitoring.

³³ Roberts, S. E., et al. "Fatal accidents and injuries among merchant seafarers worldwide." *Occupational medicine* 64.4 (2014): 259-266.

³⁴ EMSA Annual Overview of Marine Casualties and Incidents 2015

³⁵ European Union Maritime Security Strategy, Council of the European Union, 11205/14, Brussels, 24 June 2014.

- Need for a new integrated information management system to enable the identification, monitoring, tracking and reporting of all vessels at sea and on inland waterways. Such a system would be part of the e-Maritime Initiative and develop into an integrated EU system providing e-services at the different levels of the transport chain. In that regard, the system should be able to interface with the e-Freight, e-Customs and Intelligent Transport Systems. These systems are important components of the CAT framework for waterborne transport.

The communication from the Commission on inland waterways also highlights the following issue:

- Cities should take freight and waste by inland waterway transport fully into account in their Sustainable Urban Mobility Plans and strategies on city logistics. One can here also add passenger traffic, although this will be a relatively small part of the total transport work. As for many of the inland waterway issues, CAT can contribute significantly to making this mode more competitive against other modes and in particular trucks.

Furthermore, information exchange is considered a key enabler for the increased use of inland waterway transport. During the past decade the European Commission, Member States and infrastructure operators worked together to define, build and deploy River Information Services (RIS) to facilitate navigation and information exchange between transport operators and infrastructure managers. Currently a new approach is envisaged to interconnect information on infrastructure, people, vessels, management, operations and cargo. The approach consists of two interlinked concepts: ‘Digital Inland Waterway Area’ (DINA) and ‘Digital Multimodal Nodes’ (DMN). DINA and DMN shall build on the achievements of River Information Services and related developments in other modes of transport³⁶.

Inland waterways is one of the areas where deployment of harmonised ITS system outside the road sector has known one of the most widespread penetrations. Yet, there is scope for reaping far more benefits if RIS is further developed in a broader context, focusing not only on infrastructure-related aspects but also on cargo, people, operations and craft. Approaches needs to be developed for interlinking data from various sources, by improving data gathering through smart, monitoring-enabled vessels and cargo, by linking workers-related data with vessel operations, by developing ITS-enabled tools for supporting vessel-operations and by devising strategies for improving data collection, management and broader use of inland waterway related data including also in interconnection with ITS systems covering other modes of transport.

³⁶ http://www.ris.eu/news/dina/digital_inland_waterway_area

We expect that the following CAT developments have significant impacts on the above objectives:

- **Ship Automation and Ship Autonomy:** Safety levels will be increased by removing crew from a dangerous working place and by automating operations that are prone to human error. Further improvements will be achieved by improving technical condition monitoring. Reduction of human errors and technical malfunctions will directly have a positive effect on 91% of today's serious incidents, according to the EMSA safety report.
- **Traffic Management and Integrated Logistics:** These developments are able to improve the traffic situation, enable timely planning and fewer changes in plans. Sea traffic management in particular has a large potential for reducing maritime risks. The Mona Lisa 2.0 project quotes potential risk reduction factors in the ranges from 30 to 60% in selected navigational tasks³⁷.
- **Digital Connectivity:** This is a prerequisite for all other improvements, but will not in itself improve safety or security. Cyber security for digital communication, however, is a major concern.

With increasing automation, there is an increasing risk of cyber-attacks on the ships. A possible scenario is that one of the large ports are blocked by remotely controlling a ship to ground in the narrow port approach and by that stopping large parts of Europe's trade and imports. Proper handling of cyber-security is a prerequisite for safe use of automation. If cyber security is not sufficiently well implemented, this can negate all positive effects as well as create new and highly critical risks. Cyber security must be a high priority development.

Inland waterways will also benefit from the above improvements. One should also note that transfer of dangerous cargo from road to inland waterways could greatly reduce the risk of major accidents as well as reduce the consequences of any accident that may happen.

³⁷ ML2 D2.3.1 STM The Target Concept Deliverable, MONALISA 2.0 (<http://stmvalidation.eu/documents/>).

3. Baseline and State-of-the-Art

The aim of this document is to *produce a roadmap and recommendations for guiding the development and implementation process for CAT* related systems and technologies across all transport modes. After having set the scene with an *overview of the likely contributions* of CAT to the Energy Union and decarbonisation, growth and competitiveness of the EU, and safety and other related issues, the next step is to identify the *baseline and the state-of-the-art*. This process has included gathering information on *technology development*, and related *roadmaps and policy documents*. Based on this information, *research gaps and deployment barriers* have then been identified.

3.1 Technology Development

The levels of maturity, acceptance and real-life implementation of technologies and systems operating concepts for both the automation and the connectivity element *vary largely between individual modes*. Despite the current interest in these technologies, *some applications have already been in use for a considerable time*. Commercial aircraft have had an element of automation for decades and some metro lines and airport people-movers have also been fully automated for a long time. The *advent of big data* together with relatively cheap and ubiquitous *communication infrastructure* has recently given a *large boost to the connectivity element of vehicle automation*. The following sections will summarise the level of *technology development* and *likely future trends* for each of the modes.

Road Transport

This analysis focusses on systems and technologies with medium to full automation (SAE Levels 3 to 5³⁸) as well as technologies which enable connectivity. For this analysis, the systems and technologies being developed, tested, brought to the market, and being implemented and used will be categorised as follows.

Mode	Trip distance	
	< 20 km	≥ 20 km
<i>Passenger</i>	Short distance transport of people; often in urban areas with a mixture of private cars, shared cars and public transport.	Longer distance transport of people; often involves inter-urban and/or rural sections
<i>Freight</i>	First/last-mile freight delivery solutions	Heavy Goods Vehicles (HGV) on motorways but also on rural and inter-urban roads

Below key technology developments will be described according to these 4 categories, followed by some cross-cutting considerations.

³⁸ AUTOMATED DRIVING LEVELS OF DRIVING AUTOMATION ARE DEFINED IN NEW SAE INTERNATIONAL STANDARD J3016, http://www.sae.org/misc/pdfs/automated_driving.pdf

- *Short distance transport of people:*

Key in this category is the **urban environment** and the related suburban area. It currently is the **most complex** environment for CAT, involving many (types of) stakeholders, infrastructures, cultures and end users. The following two major developments should be distinguished here in the State of the Art and future trends:

Based on **mainly existing vehicles and infrastructure:**

- More and more car manufacturers offer partial automation technologies for urban application. The best known applications are parking assist systems, currently quickly evolving from Park Distance Control via Park Assistance to fully automated Parking Systems.
- Furthermore, important innovations that have been implemented include ACC (Adaptive Cruise Control) with Stop & Go, no longer only for highway applications but also at low speed driving.
- The first versions of lower speed Lane Keeping Assistance are also penetrating the market. Important developments are being worked on, to actively use the information from the infrastructure and the traffic management system for dedicated use in cars.
- A major effort is needed to merge the different (types of) systems into a vehicle concept, ready for use in different geographic zones but also for longer distance transport. Furthermore, safety applications with a time critical component are not yet ready for market introduction.
- The application of shared mobility services is finding its way into these vehicles and their users, as car ownership, especially in urban areas, is decreasing (Uber, blablacar, Talk2Go, Car2Go, DriveNow, Zipcar, cambio). This societal trend can be strengthened by CAT due to the increased availability and reliability of transport data and transport needs and available solutions to an emerging transport demand. Though, on the other hand, there is the potential risk and downside of this trend, of the increasing demand of individual trips.

Based on **new vehicles and dedicated infrastructures:**

- Driven mainly by government funded research; developing and demonstrating automation of specialised vehicles, supplied outside the traditional vehicle manufacturing industry, have been carried out in the EU since 2001.
- A key project in this respect was the EC funded project CityMobil, with people mover demo tracks in Castellon, Rome and Heathrow. Both the UK and France are also currently conducting highly visible demonstrations of these systems. Although most demonstrations so far have been on a small scale, i.e. a line or small loop, the first of these systems, notably in the Netherlands, have been successfully implemented in public areas.
- These systems can provide user-friendly public transport, often in areas where conventional public transport services are costly to operate. These systems normally use a dedicated track and therefore have limited interaction with other traffic, mostly with pedestrians.
- The systems normally go under the name of Automated People Movers (APM), although other terms such as Cybercars (see Automated Road Transport Systems (ARTS, see CityMobil2) or PRTs (Public Rapid Transport systems) are also used. These APMs operate on high frequency or on demand and have the potential to decrease car traffic and emissions, and increase the efficiency of (public) transit nodes, parking facilities and land use in urban areas (if the track is well positioned). On the other hand can these systems be competing with urban cycling and walking as transport modes.
- While often being highly or fully automated, these APMs have only limited connectivity. In the future, such systems hold the promise of operating on-demand, e.g. providing first/last-mile connections e.g. for airports, business parcs, campus areas or city centres. EU funded projects

such as CityMobil 1 (www.citymobil-project.eu) and 2 (www.citymobil2.eu) have demonstrated these last mile vehicles, unmanned mode (SAE Level 4), although an operator is present for legal and safety reasons. Travelling at around 10-15 kph, to maintain road user safety, the speed of most of these systems is currently too low to be attractive, and fails to be competitive against conventional public transport systems.

- Part of the research conducted by these projects has addressed business cases, (functional) safety, legal and liability issues, as well as the operational requirements necessary to succeed when introduced in already existing public transport systems. Several OEMs of last mile shuttles have already appeared in the market and are willing to lead the first wave of non-research, commercially available and roadworthy transportation.

Some developments *do not fit into the indicated categories*, but should be mentioned here as well. They are closest linked to the above, but are not limited to short distance transport only:

- **Cybercars** are small automated vehicles for individual or collective transport of people and goods. They can be fully automated on demand transport systems that under normal operating conditions do not require human interaction; fully autonomous or make use of information from a traffic control centre, information from the infrastructure or information from other road users; small vehicles, either for individual transport (1-4 people) or for transport of small groups (up to 20 people); and using either a separated infrastructure or a shared space.
- **High-Tech Buses** such as the Phileas bus³⁹, are buses on rubber wheels, operating more like trams than like traditional buses; they are vehicles for mass transport (more than 20 people); use an infrastructure (with or without guidance units (transponders or magnets) in the road), which can be either exclusive for the buses or shared with other road users; can use various types of automated systems, either for guidance or for driver assistance; and always have a driver, who can take over control of the vehicle at any time, allowing the vehicles to use the public road.

- *Longer distance transport of people:*

Many vehicle brands are working on the development and roll-out of vehicles with increasingly higher levels of automation, paving the way from current Advanced Driver Assistance Systems (ADAS) systems towards full vehicle automation. Apart from the lower levels of automation, such as anti-lock braking, lane keeping and cruise control, a large boost to this development was given by the emergence of so-called C-ACC systems: Cooperative Adaptive Cruise Control. This was also the first true application of communication technologies in road vehicles, quickly followed by forward collision warning systems and systems delivering information on events and situations on the road ahead, based on experiences from earlier vehicles on the road. The AdaptIVe⁴⁰ project is developing several of these new higher SAE level ADAS functions, targeting both long and short distance passenger transport, safety and comfort.

One of the most important projects, accelerating developments in this area, was the EC-funded project PREVENT, with a main focus on safety. Current developments show several traffic jam assist systems, as well as various levels (Connected) Adaptive Cruise Control. The underlying assumption here is that the private car in its current concept will prevail during the next decade or so, with only the added option that an autopilot function can be activated.

It is especially critical to address the long transition that mobility will face, with several levels of automation sharing public roads for many decades. Human factors, addressing the relationship and

³⁹ See [https://en.wikipedia.org/wiki/Phileas_\(public_transport\)](https://en.wikipedia.org/wiki/Phileas_(public_transport))

⁴⁰ <https://www.adaptive-ip.eu/>

interaction between vehicles and drivers, occupants and (vulnerable) road users are of key importance from research, industry and policy making point of view. In some cases it can also be observed that traditional car manufacturers are slowly branching out into also seeing themselves as more general mobility providers. Examples of this paradigm shift include BMW's Drive Now or Daimler's Car2Go car sharing schemes, or the joint ventures between GM and Lyft and the Google, Uber, Ford coalition. This is covered in more extent in the STRIA Roadmap on New Transport and Mobility Services.

- First/ last-mile freight delivery solutions:

First developments are under way for deploying small automated vehicles (sometimes called road drones) for urban freight distribution. Although currently a smaller niche application compared to the examples above, in the longer term, this might develop into a viable addition to the wider freight and logistics sector.

Due to the sharp timing demands valid in this sector, in many vehicles some sort of communication system is integrated. The further use of this for safe, clean and fast (urban) freight delivery need to be implemented. A challenging part here is the scattered market and varying local (governmental) demands.

Furthermore, for a successful implementation of first/ last mile freight delivery in a cooperative and/or automated mode, a solid connection to other transport modes like rail and waterborne are essential. An important likely future trend will be the combination of this type of transport also with short distance transport of people. Another need is the need for further standardization of modular load units (boxes, pallets, containers), transference processes between vehicles and for goods delivering, which will largely affect effective automation of cargo transfer and cross-modality, both for first/last-mile freight delivery and long distance transport.

- Heavy Goods Vehicles (HGVs) on motorways:

Truck platooning is an example of both connected and automated transport. Clear benefits in terms of road safety, emissions, and road capacity have been proven through the automation and operation at minimum headways. Several EU projects (i.e. SARTRE, COMPANION, CONVOI, AutoNET2030, iGAME) have tackled the technical challenges of road trains in order to leverage its benefits. These projects have implemented different levels of automation for the vehicle control and all of them heavily rely in the use of cooperative systems and connectivity to improve the platooning performance and facilitate its integration to the logistics chain in an efficient, safe way.

Also driven and (partially) performed by industry in conjunction with government funded efforts, is the testing of automated HGVs on motorways in many countries including the USA, Japan, and many EU countries. A highly visible example of this is the recent Truck Platooning Challenge⁴¹, organised by the Dutch Government as part of their EU Presidency in the first half of 2016.

Potential obstacles to widespread real-world roll out include relevant regulation, cross-border legal fragmentation, fragmentation of technologies and equipment, appropriate business models and cases for sharing benefits in a platoon among transport companies and necessary infrastructure changes.

⁴¹ <https://www.eutruckplatooning.com/default.aspx> European Truck Platooning Challenge 2016

Creating next generation mobility; Lessons Learnt

The Netherlands launched the European Truck Platooning Challenge during its 2016 presidency of the Council of the European Union in 2016. Six brands - DAF Trucks, Daimler Trucks, Iveco, MAN Truck & Bus, Scania and Volvo Group – drove semi-automated trucks in platoons, on public roads from several European cities to the Netherlands. The aim was to bring platooning one step closer to implementation.

Specific tailored solutions will also have to be developed for the transfer of goods from these vehicles on specific corridors to other (automated or manually operated) road vehicles and/ or modes.

Automated HGVs will also need the support of current and new ITS technologies, which together with logistics-related ICT, should be able to provide cost-benefit of platooning and thus enable European competitive logistics. The most likely future trend is that governments will allow for some larger scale pilots for truck platooning with a strong emphasis on the connectivity side of the technology.

This needs to be coordinated in some way to ensure seamless, efficient and safe multi-brand platooning in cross-border situations taking into account national regulation and a potential harmonization to enable European level deployment.

- Cross category future trends

Points valid for most of the above mentioned categories include:

- Highly developed, intuitive, user focused HMI for efficient communication between the vehicle and its occupants
- The vehicle and its parts are affordable, sustainable and resilient to sudden and unexpected weather and environmental changes

Furthermore, whereas in the above description the issue of *cooperative mobility* has only been dealt with indirectly with connectivity as an enabling technology for vehicle automation, cooperative mobility is now increasingly emerging as a much more prominent aspect. This is mainly related to the topic of *deep-learning*, which is now increasingly being used.

Whilst in the past, due to limits in computing power, all objects an automated vehicle might encounter had to be pre-defined, which is very time consuming. Through deep-learning processed by a large number of vehicles can be communicated to a cloud-based database for off-line processing. Based on this algorithms can then be updated and these updates can be sent back to all vehicles, and so on, with the system thus self-learning and improving.

Rail Transport

CAT technologies are already well embedded in selected market segments of rail transport, specifically in metro systems. The highest grade of automation (GoA) 4 – a fully automated driverless rail systems exist today in metro systems, e.g. in Copenhagen or Paris. Next to automatic operation based on moving block principle (creating in real-time safe distances between moving vehicles), the GoA 4 system is responsible for door closing control, dealing with obstacles on track during the journey and emergencies. It should be noted that this highest GoA level was mainly introduced on newly constructed metro lines, in an isolated environment, not accessible for third parties. Solutions were not standardised and expensive.

The technological progress in the nineties caused that in other market segments of rail-bounded transport (LRT, suburban rail, long distance rail) CAT technologies based on common standards were developed and deployed, like CBTC systems or ETCS and GSM-R. However, a very diversified European rail landscape, characterised by various safety and operational principles, technical solutions as well life-cycle stages, causes that the process of implementing CAT technologies is progressing slowly, and this lowers competitiveness of railway sector.

The rail sector recognises that a new era of ‘Digital Railway’ is needed in order to prepare the sector for the general digitalisation of the economy. Major European stakeholders, including DB AG, SNCF and Network Rail initiated digitalisation action plans. German and French rail industries agreed recently to work closely together on digital innovations. The recently elaborated ERRAC roadmaps for the railway sector support the acceleration of the deployment of CAT solutions and a wider implementation of higher grade of automation to achieve the following objectives:

- improvement of rail sector performance and reliability
- reduction of life-cycle costs
- improving safety characteristics by reduction of human errors
- better accessibility for all types of passengers
- smooth freight handling

The realization of these objectives may enable rail to be the most environmentally-friendly mode of transport as well as the one with the highest share, within public transport. This is the most important rail sector challenge for the next 35 years.

However, the deployment of higher grades of automation and other CAT related solutions in railways are hindered by:

- economic life cycle cost (LCC) considerations: when the existing systems should be replaced
- variety 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
- short life-cycles of new technologies and related issues of backwards compatibility
- limits of connectivity using the existing GSM-R standard

The long life expectancy for railway products and the differences in their age in various European countries slow down the speed of the emerging CAT technologies deployment. Also, a variety of operational rules and technical solutions per country make it difficult to define optimum deployment method valid for all stakeholders.

Railway competitiveness against other modes of transport depends to a larger extend on economies of scale in deploying new technologies and an overall acceptance of standardisation of the technical requirements and operational rules on European level.

Without a wide deployment, the impact of CAT technologies on policy goals will stay limited. The existing state of the art and ongoing R&I efforts under the flagship of European Commissions’ Shift2Rail Joint Undertaking (JU), creates a promising perspective for an automated and connected rail technological roadmap. Moreover, the recently created technology & innovation roadmaps of ERRAC are used as a guideline, to establish a dedicated roadmap related to automation & connectivity in the rail domain.

The existing Strategic Rail Research Innovation Agenda (SRRIA) and related roadmaps for various parts of rail-bounded systems address directly and indirectly several aspects of automation and connectivity. Already today the on-going R&I efforts under Shift2Rail are 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
 - Increase rail attractiveness (passenger & freight) by improving connectivity, passenger information and experience, freight data handling, achieving shorter travel times
 - Improve competitiveness by reducing 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 leveraging new technologies such as digitalization, new materials, big data, energy storage and efficiency.

In realising these objectives and challenges, aspects of automation and connectivity play a crucial role. The existing state of the art with regard to sector vision, related R&I policy measures and the ongoing Shift2Rail JU activities creates a good reference point for an automated and connected roadmap for the part of rail-bounded transport. A better inclusion of metro's and trams in the overall R&I measures would facilitate achieving the above objectives on a larger scale within the future smart cities. Emerging new mobility concepts using rail environment could contribute to increased multi-modal integration.

Air Transport

In the conventional aviation sector, CAT is progressively introduced in an evolutionary model. The prime reasons for introducing more automation are increased safety levels, increased throughput, effectiveness and cost efficiency. Efficiency in the use of fuel, which represents around 25% of an airline's operating cost, contributes directly to all except safety.

Improved connectivity and increased automation are instrumental although not sufficient to deliver the innovative products and services to air transport and its passengers required if Europe wants to continue to be a leader in the air transport sector.

CAT will also change air transport's operational environment, from urban areas if low-noise air transport systems supported by CAT develop to remote areas where the number of new automated air services to citizens could increase enormously thanks to these new technologies and new business models.

The automation and connectivity of the conventional, and future, aviation sector will take advantage of the System-Wide Information management (SWIM) system developed under the SESAR programme. This "big-data internet of the air" will allow all players in the industry - airplanes, airlines, airports, air-navigation service providers (ANSPs), weather centres, etc. - to supply and use each other's data. For example, an ANSP could re-route one airplane to reduce climate impact, by making use of up-to-the-minute weather information produced by a weather centre on the basis of data downloaded from a preceding airplane.

Automation and connectivity are increasingly dependent on virtualisation. The latter supported by appropriate data management processes, will play a major role in the future air transport system to deliver currently unachievable operational improvements.

Recent and expected future connectivity and automation evolutions are likely to rapidly bring fundamental changes to the aviation sector, notably due to penetration by new players involved in other industrial sectors. Other areas (agriculture, logistics, space aircraft, stationary network-node drones, etc.) will be offered new services and will be granted access to the airspace. This revolution will significantly affect all aspects of air transport: the types and number of vehicles is expected to grow tremendously together with an increase in complexity of traffic patterns, which will require totally new traffic management solutions that rely on CAT solutions.

The variety of operations will also expand largely beyond the conventional air transport business (passengers and goods) or enhance current business segments by new options (passenger drones for short-distance travel or automated cargo air systems). Drones can improve the time-efficiency and, for some routes (lacking normal infrastructure), energy efficiency for transporting goods, though less so for passenger flows. Again, creating new opportunities will increase demand and energy consumption. Drones are also a laboratory for exploring the miniaturisation of Communication/ Navigation/ Surveillance (CNS) integrated solutions which play a key role in CAT and can bring significant benefits if transferred.

Ultimately CAT is the catalyst of a revolution moving from piloted aircraft via unmanned aircraft carrying passengers to a virtualised operating system. The new entrants also include balloons, such as those to be deployed for providing low-cost internet solutions playing a significant role in improving the connectivity of remote areas.

It is also about new zero-emission freight air vehicles performing point to point deliveries away from conventional airports. Finally, new entrants include space aircraft which may negatively impact aviation emission targets, while being essential competitiveness assets for the EU air transport industry.

Significant research has been conducted on drones, nevertheless new applications are developing at high speed in all sectors, requiring an appropriate regulatory framework for their safe and efficient integration with conventional traffic. Further research and innovation in this sector should primary focus on management of small drones in low altitude airspace, urban and remote areas, with a view to anticipating their development and producing solutions and a regulatory framework in terms of roles and responsibilities that can be expected of the air transport workforce (in particular for full autonomous vehicles). Research should also be reinforced in the area of social acceptance in particular liability and privacy issues.

With the *emergence of new traffic in the lower airspace and supra-upper airspace* (e.g. drones, space aircraft, balloons), safely managing the complexity of new traffic patterns will require acceleration in the level of automation.

In terms of CAT, *air traffic management* is evolving along the following lines in accordance with the SESAR programme and European ATM Master Plan (see section 3.2):

*“Europe’s vision for aviation builds on the notion of **trajectory-based operation** and relies on the provision of air navigation services to support the execution of the business or mission trajectory, meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations”.*

This vision is enabled by a progressive increase in the level of automation, systems integration and the implementation of virtualisation technologies as well as the use of standardised and interoperable systems.

SESAR has been instrumental in developing, in particular:

- ***New features requiring a high level of automation*** to improve ATM performance: departure, arrival and taxiing managers are being integrated based on higher levels of automation in order to improve capacity and efficiency, and to reduce flight delays. Further research is currently underway to take full account of all airport operations in the performance of the Network.
- ***Air Traffic Control (ATC)*** has been **virtualised** for decades. Although Terminal Manoeuvring Area (TMA) and en-route ATC centres are generally located within the Flight Information Region (FIR) / country they cover, they are hundreds of miles from the radars or other ATM infrastructure used to locate or provide services to the aircraft being controlled. Radar data may be taken from any radar by an ATC centre anywhere in Europe. The **system infrastructure** will gradually evolve with digital technologies, allowing air navigation service providers (ANSPs), irrespective of national borders, to plug in their operations where needed, supported by a range of information services.
- ***Remote, virtual airport control towers*** for controlling landing, take-offs and taxiing at an airport where it is too costly or logistically too difficult to provide a full local service will enable controllers to manage airport traffic at several airports at the same time enhanced visualisation techniques that can improve on reality, for example by “seeing” through fog.
- ***Virtualisation*** is also used extensively during the pre-operational stage. ATC is a safety-conscious business and new procedures and operations are generally tested in depth prior to entering into service. This testing takes place in ATC simulators where an entire virtual control centre, or more, is used by real controllers with virtual aircraft flown by real pilots. Virtualisation is heavily dependent on the provision of high integrity data and appropriate data governance mechanisms, including liability aspects.
- A System-Wide Information Management (SWIM) concept is providing **connectivity** between all airspace stakeholders and enabling data sharing between them. This will open up many more possibilities for automation in the air-traffic system and for greater efficiency and CO₂-emission reduction. SWIM could eventually be a blueprint for a transport-wide information-sharing network.
- ***“Functional Airspace Blocks” (FABs)***, which are supra-national organisations of airspace and ATM, will enable ATC centres to exceed country borders, therefore increasing the potential for virtualisation. They also have the potential to allow more optimised flight paths, but as FABs have not yet been fully realised, flight paths optimisation, and thus CO₂ reduction at network level, is limited in this respect.

In terms of CAT, the ***air vehicle is evolving towards higher levels of automation:***

- ***Smarter avionics systems*** are gradually being integrated into the cockpit with an ever increasing level of automation (auto-land, auto-throttles, flight envelope protection, electronic checklists, flight management systems optimising flight profiles in order to reduce fuel consumption or other parameters or to propose rerouting, new features are being researched for reducing runway occupancy time, etc.). Further improvements are expected through the SESAR and Clean Sky projects.
- ***Automation on board*** (if human-centred) comes together with increased levels of safety and also increased efficiency and predictability. It has also been the only option for enabling operations

when operating in low visibility conditions. Automation has been instrumental in decreasing the number of crewmembers from 5 to 2. Significant research has already been conducted on moving from a 2-pilot crew to a fully autonomous air vehicle via single pilot, optional piloted and RPAS remote pilot, notably in the context of human factors and artificial intelligence. This research effort is complemented by recent drone experience (in particular large military drones). Significant issues in terms of safety and security, social acceptance—especially for passenger aircraft – changes in roles and responsibility as well as governance are still to be addressed through research and innovation actions as well as new policy and regulatory actions.

- ***Miniaturised low-cost on-board Detect And-Avoid (DAA) systems*** allowing small drones to avoid collisions with other airspace users will be required. This automation technology could be applied, in the long term, to manned aircraft, allowing for safe manned aviation, from very large airliners to personal flying vehicles, with no pilot or controller. Significant progress has been made in this area although for some challenging environments more validation is required.
- ***Virtualisation*** is gradually being introduced at all stages (from design to maintenance) and offer great CO₂-reduction opportunities from production to decommissioning. Some examples are: new on-board displays with data-based information for enhanced vision operations (e.g. SVS/CVS); licensing and recurrent training on simulators (aircraft pilots are trained on full 4-D virtual aircraft simulators mounted on hydraulic jacks that offer a very good level of reality); virtual certification /design / maintenance. Further steps in virtualisation are necessary to deliver competitive products which will bring the expected CO₂ emission reductions. Validation and certification of the products as well as safety/security of the operations they support remains on the critical path.
- All aircraft are connected to ATC centres through radio, with information being shared through having many aircraft on the same frequency. This technology is not fit-for-purpose in tomorrow's world. However, modern data ***connectivity in conventional air transport*** is developing at a slow pace compared with other domains of activity. One of the reasons for this lies in the criticality and complexity of operations and the safety and security challenges it brings to the current certification process. Another reason comes from the global nature of its operations (e.g. over very deserted or remote areas) and the long distances covered. To help accelerate its development new thinking regarding the certification process is needed. For the drone sector connectivity is and will become even more, essential in management of the fleet (e.g. RPAS operators and others, global tracking from Radars / ADS-B / ADS-C to satellite monitoring, collision avoidance (TCAS): connection between aircraft, being extended (TCAS-U) to deal with unmanned air vehicles).
- ***Connectivity also offers new services to passengers***: on-board Wi-Fi – being implemented by many airlines; satellite phones; innovative ground processes based on advanced identification and payment systems (e.g. based on mobile devices, block-chain technology, biometrics); transport ticketing, significantly improved customer information and handling system; and to the air transport industry (e.g. engine performance and aircraft monitoring; EFB extended use; CPDLC.. New services which could contribute to CO₂ reductions notably those linked to measurement and prediction of environmental condition, pollution, monitoring, and dynamic flight path dynamic reconfiguration would need to be developed and standardised.

Waterborne Transport

Waterborne transport is relatively advanced in the adoption of CAT technologies. Within the main development areas a brief description of the state of the art is as follows:

- **Ship Automation** is well advanced with most modern ships and vessels being equipped with target detecting radars, automated warnings for crossing traffic as well as autopilots and track pilots making use of satellite positioning systems. Automatic Identification System (AIS) transponders on many vessels on sea or inland waterways send position and speed data to other ships and shore to enable better shore support and improved anti-collision decision support. Technical systems on board have a high degree of automation and today, all ship systems can in principle be remotely controlled from the bridge or even from shore, although the latter is not generally allowed by the relevant authorities today.
- **Ship Autonomy** is a new field with little technology available today. Some demonstrations have been made of suitable technology, e.g. in the MUNIN project⁴², but this is still on a low technology readiness level. Automation systems, such as dynamic positioning, contains some elements of autonomy. Automated berthing has been demonstrated in some special cases.
- **Traffic Management** is simplified by many ships having AIS transponders. Shore support in the form of River Information Services (RIS) or Vessel Traffic Services (VTS) for sea areas is common, although VTS only provides monitoring and voluntary guidance. Past and ongoing EU-projects, such as Mona Lisa and STM, are looking into more advanced traffic management schemes. Inland waterway projects such as RIS COMEX and CoRISMa are looking into further harmonisation of River Information Services and will bring RIS one step further to integration with other transport modes. Important objectives are to minimize port and fairway congestion and to enable just in time arrivals. Some systems have been tested, but legislative support for giving more direct instructions to ships is missing.
- **Integrated logistics system:** Developments are under way to optimize use of different transport modalities and by that reduce total emissions. This is of particular interest to waterborne vessels due to their lower flexibility inherent in relatively large transport units and fixed terminal points (ports). There is also much development work going on in internal integration and facilitation in the trade domain⁴³. This also includes harmonization of digital data formats. However, a major concern is how the waterborne transport domain can be integrated in this work: There is a need to develop improved digital connectivity between these domains.
- **Digital Connectivity** is a prerequisite for all above improvements. Today, digital connectivity is available on the physical carrier level (satellite or land based mobile communication) and it is expected that commercial interests will provide ever increasing capacity and coverage as demand from paying customers increase. Shipping is also dependent on free-for-use safety communication on the VHF band. This must be maintained by the public. Note that air traffic communication may have similar challenges in this area. As noted above and elsewhere, protocol and interoperability standards are essential. Exchanging digital data is of no use if the data cannot be understood by the receiver. Cyber-security in the waterborne domain is improving, but it is an area that requires much more effort.
- **Physical Connectivity** is mostly outside the scope of CAT, but is included here for completeness. Automation of shipping, including the unmanned ship, requires significant investments in physical port and transshipment infrastructure, e.g. in berthing, mooring, port services hook-up and cargo handling. Automatic mooring systems are already available, based on hooks, vacuum or magnetic attachment to the ship. These systems must be integrated with on board automation.

⁴² See <http://www.unmanned-ship.org>

⁴³ See e.g. <http://www.unece.org/tradewelcome/trade-programme.html> and http://ec.europa.eu/priorities/digital-single-market_en

The waterborne sector has seen much and very good developments since the introduction of computers and digital automation on ships around 1970. However, there is still an unacceptably high accident rate and significant potential for reduced energy consumption, so further developments are still needed. New developments of CAT in the waterborne sector is expected to lead to the following main goals:

- **"Shipping 4.0"**⁴⁴ is the expected adoption of Industry 4.0⁴⁵ concepts into deep sea, coastal and inland shipping, leading to much more efficient and integrated technical systems on board and on shore. This includes technology such as autonomy, Internet of Things and Services, cyber-physical systems and big data. This will improve safety and energy efficiency on the ship by increasing the level of automation and shore based support. It will also provide better decision support to ship officers and allow periodically unmanned operations of vessels - **autonomous ship operation**.
- **Unmanned ships** is a parallel development of "shipping 4.0" technology for fully unmanned ships. This includes new ship designs and port infrastructure as well as more advanced autonomous control functions. For small vessels, e.g. on inland waterways, this can happen in a relatively short time frame, while for large ocean going ships it is expected that this development will be via increasing operator support and periodically unmanned operation. Unmanned ships will decrease energy use due to no hotel section and more efficient ship constructions. The technology will also enable major changes in how waterborne transport services and chains can be set up, including completely new ship concepts, which will also aid the mode change from road to water by, e.g. introducing smaller, more flexible and low operational cost vessels.
- **Integrated logistics and transport system** represent the final integration of the new and emerging waterborne transport system into the other transport systems and the supply and production chains. This will allow full optimization of the transport operations into the supply chains and can dramatically reduce energy consumption. The optimization is expected to be driven from the supply chain perspective. For waterborne CAT, the focus should mainly be on seamless physical and digital connectivity between ship operations, traffic management systems and supply and trade chains systems.

Each of these development trends has the potential to change the waterborne business area radically and are in their nature examples of "disruptive technology". Disruptive technologies has the potential of creating major changes in businesses and business models that are most likely necessary to achieve the long-term goal of 50% reduction in greenhouse gas emissions from the sector.

⁴⁴ See <http://zmttest.swzonline.nl/news/7961/shipping-40-smm>

⁴⁵ See, e.g. Schwab, Klaus. "The fourth industrial revolution.", World Economic Forum, Geneva 2016. Brief introduction on: <https://www.weforum.org/pages/the-fourth-industrial-revolution-by-klaus-schwab/>

3.2 Roadmaps and Policy Documents

Whilst the present roadmap has a *very specific focus* on R&I and other policy support activities for the deployment of connectivity and automation technologies across all transport modes at EU level, *many other mainly mode-specific roadmaps and policy documents* have recently been put together by a number of institutions. In order to avoid overlaps, the main roadmaps and policy documents have been reviewed and their key messages analysed. The key policy documents, roadmaps and initiatives are listed below for each of the modes.

Road Transport

- **ERTRAC Automated Driving Roadmap, July 2015:** focus on road, cars and trucks; urban and inter-urban transport, showing current and foreseeable developments from a mainly technology perspective
- **ACEA Strategy Paper on Connectivity, April 2016;** showing the need for the sector to cooperate in the introduction of innovative solutions to the market, promoting European competitiveness.
- **Pathway to Driverless Cars: A code of practice for testing.** Provides an overview of recommendations for testing automated vehicles on public road in the UK, to ensure safety is maintained in the process.
- **Research for TRAN-Committee: Self-piloted cars: the future of road transport? March 2016:** analysis of the development of automated vehicles inside and outside the EU, as well as key research projects and large scale testing.
- **German Government Strategy for Automated and Connected Driving, September 2015:** focus on road, mainly personal cars, 2 scenarios.
- **Driver at the wheel? Self-driving vehicles and the traffic and transport system of the future, October 2015, KiM Netherlands Institute for Transport Policy Analysis:** envisaging four possible scenarios for traffic and transport systems of the future as well as their (dis)advantages. Also takes into account also developments towards the sharing economy into account.
- **VDE/ VDI European Roadmap Smart Systems for Automated Driving, April 2015:** Car only, based on OEM suppliers.
- **iMobility Forum Automation working Group** roadmap, delivered by many road stakeholders. Used as input also for the ERTRAC Automation roadmap.
- **C-ITS platform report, EC, January 2016:** focus on road, traffic, stakeholder analysis; working on the deployment needs for C-ITS systems. **The C-ITS Platform** addresses the main barriers and enablers with a view to providing policy recommendations to the EC for the development of a Communication on the Deployment of C-ITS.
- **Automation: From Driver Assistance Systems to Automated Driving, September 2015, VDA** (Verband der Automobilindustrie): focus on the combination of automation and the trend towards urbanisation as well as the opportunities for an internationally competitive German industry

- ***New autoMobility; The Future World of Automated Road Traffic, acatech, September 2015;*** drafting so-called autoMobility scenarios up to 2030 and calling for an integrated approach of connected and automated transport, focusses on Germany.
- ***GEAR2030:*** European Commission High Level Group focusing on the adaptation of the value chain to new global challenges, the automated and connected vehicles trade, and international harmonisation and global competitiveness.
- ***Oettinger Roundtable:*** Cross-sectorial dialogue between automotive and telecommunication / IT industry to join forces on fast, coordinated deployment of future-proof communication systems and increasing levels of automated driving. The aim is to strengthen Europe's leading position in connected and automated transport and to accelerate roll-out of increasing levels of automation on Europe's roads. This initiative is led by Commissioner Oettinger, responsible for Digital Economy and Digital Society.

Rail Transport

The European Commission is committed to a Europe 2020 strategy based on smart, sustainable and inclusive growth. This includes achieving a more competitive and resource-efficient European transport system with a view to addressing major societal issues such as rising traffic demand, congestion, security of energy supply and climate change.

To achieve this, the Commission's 2011 Transport White Paper (“Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system”) sets out a number of key goals to strengthen the role of rail in the transport system, given rail's inherent advantages in terms of environmental performance, land use, energy consumption and safety.

With a long term goal to improve rail competitiveness and creation of a Single European Transport Area, the European rail sector mobilises its research and innovation efforts through the European Rail Research Advisory Council (ERRAC) and the Shift2Rail Joint Undertaking.

ERRAC, has issued several strategic documents aiming at fostering innovation and guiding long-term research efforts, including Rail Route 2050, and the Strategic Rail Research and Innovation Agenda (SRRIA).

The works of ERRAC cover all forms of rail transport from conventional, high speed and freight applications to urban and regional services. The CAT aspects are directly and indirectly addressed in the recently (2016) published technology and innovation long-term roadmaps (issued by ERRAC / FosterRail):

- Customer experience roadmap
- Strategy and economics roadmap
- Energy and environment roadmap
- Safety roadmap
- Security roadmap
- Control, command and communication roadmap
- Infrastructure roadmap
- Rolling stock roadmap
- IT and other enabling technologies Roadmap

- Training and education roadmap

Shift2Rail is the first common European rail initiative, led mainly by large rail technology suppliers and railways to seek focused research and innovation (R&I) and a fast deployment of market-driven solutions. It aims at creating the necessary technology, within the Horizon2020 period, to enable completion of the Single European Railway Area (SERA).

The Shift2Rail general objectives from the Shift2Rail Regulations and Master Plan are:

- Achieve the Single European Railway Area through the removal of remaining technical obstacles holding back the rail sector in terms of interoperability and through the transition to a more integrated, efficient and safe EU railway market, guaranteeing the proper interoperability of technical solutions.
- Radically enhance the attractiveness and competitiveness of the European railway system to ensure a modal shift towards rail through a faster and less costly transition to a more attractive, user-friendly (including for persons with reduced mobility), efficient, reliable, re-designable and sustainable European rail system.
- Help the European rail industry to retain and consolidate its leadership on the global market for rail products and services by ensuring that R&I activities and results can provide a competitive global advantage to EU industries vis-à-vis foreign competition and by stimulating and accelerating the market uptake of innovative technologies.

Air Transport

In air transport several roadmaps and R&I agendas/programmes exist already. They include:

- ***Flightpath 2050***, which defines high-level goals, for each of the 5 key challenges of the aviation sector (mobility, competitiveness, environment and energy, safety and security, resources) for 2050.
- ***The ACARE Strategic Research and Innovation Agenda (SRIA)*** (<http://www.acare4europe.com/sria>), supporting material for the realisation of the Flightpath 2050 goals. Strategic research and innovation actions as well as policy needs for the aviation sector have been identified for the 2020, 2035 and 2050 time horizons. These R&I actions are being used to drive the aviation research and innovation programmes notably H2020, Clean Sky and SESAR. An update of the SRIA is planned for June 2017.
- ***The Clean Sky programme*** is the most ambitious aeronautical research programme ever launched in Europe. Its mission is to develop breakthrough technologies to significantly increase the environmental performances of airplanes and air transport, resulting in less noisy and more fuel efficient aircraft. As part of its Systems for Green Operations ITD, the Clean Sky programme includes actions to assess, design, build and test new aircraft system technologies and architectures in the two areas of Management of Aircraft Energy (MAE), and Management of Aircraft Trajectory and Mission (MTM).
- ***The SESAR project , based on the ATM Masterplan, and the SESAR deployment programme*** will significantly contribute to the Flight Path 2050 air traffic management goals (mainly in the mobility, safety & environment challenges). The Masterplan includes the European ATM standards and regulations, and roadmaps. SESAR 1 and SESAR 2020 together with the SESAR

deployment programme will deliver a significant number of ATM solutions based on CAT at local and network levels.

The first set of deployed solutions, heavily dependent on CAT capabilities and captured under the Pilot Common Project implementation regulation (EU) No 716/2014 are:

- Extended Arrival Management and Performance-Based Navigation in the High Density Terminal Manoeuvring Areas
- Airport Integration and Throughput
- Flexible Airspace Management and Free Routes
- Network Collaborative Management
- Initial System Wide Information Management (SWIM)
- Initial Trajectory Information Sharing

The SESAR work programmes also include a number of UAS / RPAS demonstrators as well as specific research projects to tackle their integration in ATM. UAS are not addressed in the SESAR industrial project but could be considered as part of the exploratory research calls. Connectivity is limited to the ATM connectivity needs.

- ***The International Civil Aviation Organisation (ICAO) Global Air Navigation Plan (GANP):*** The GANP represents a rolling, 15 year strategic methodology which leverages existing technologies and anticipates future developments based on State/industry agreed operational objectives. “Block Upgrades” are organised in five year time increments starting in 2013 and continuing through 2028 and beyond. This structured approach provides a basis for sound investment strategies and will generate commitment from States, equipment manufacturers, operators and service providers.
- ***The Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System– (June 2013 – Final report from the European RPAS Steering Group)*** identifies the actions that should be taken in the areas of regulation, research and the social impact of RPAS, taking into account the necessary coordination and interdependencies between these three streams of activity. The ***EUROCONTROL RPAS R&I dashboard*** provides an overview of the research conducted on RPAS.
- ***The Space Strategy (under development)*** will be instrumental in providing the space infrastructure supporting a number of CAT services to air transport in the domains of CNS, new types of operation, safety and security, and spectrum needs.

The purpose of the STRIA CAT roadmap is to focus on CAT developments only, and moreover on the multimodal synergies of technological, operational or policy actions primarily with a view to accelerating air transport decarbonisation and growth. . However, as CAT is an enabling and cross-cutting topic in many aviation-specific action areas, reference should also be made to the above-mentioned documents to get a full picture of all CAT-related aspects. The STRIA cannot address all of these.

Waterborne Transport

There are a number of EU policy documents related to waterborne transport and CAT objectives. The main documents referenced in this paper are:

- Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: “A European Strategy for Marine and Maritime Research. A coherent European Research Area framework in support of a sustainable use of oceans and seas.” COM (2008) 534.

- “The European Union's maritime transport policy for 2018”, MEMO/09/16, Brussels, 21. January 2009.
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: “Strategic goals and recommendations for the EU’s maritime transport policy until 2018”. COM (2009) 8.
- White Paper: “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system.” Brussels, 28.3.2011. COM (2011) 144 final.
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: “Towards quality inland waterway transport – NAIADES II”. SWD (2013) 324.
- “European Union Maritime Security Strategy”, Council of the European Union, 11205/14, Brussels, 24 June 2014.

There are some other important documents that have not been referenced in this paper as relevant CAT related objectives in these are also mentioned in the references that have been used:

- European Commission Green Paper “Towards a future Maritime Policy for the Union”: a European vision for the oceans and seas COM (2006) 275
- “Blue Book – An Integrated Maritime Policy for the European Union”, COM (2007) 574.
- The EU’s freight transport agenda: Boosting the efficiency, integration and sustainability of freight transport in Europe, COM/2007/0606.
- Communication and action plan of 21 January 2009 with a view to establishing a European maritime transport space without barriers COM (2009) 10.
- European Commission Communication: A simple and paperless environment for Customs and Trade COM/2003/452.

In addition to these, there are other policy developing initiatives from different groups of private or public organisations that are relevant:

- **The Waterborne Technology Platform** (<http://www.waterborne-tp.org/>): The European Technology Platform WATERBORNE is a forum where all stakeholders from the waterborne sector (sea & inland) define and share a common Vision, Strategic Research Agenda and Implementation Plan to drive the necessary waterborne transport research and innovation efforts forward. A special roadmap has also been provided for Blue Growth by the Waterborne TP. This is mainly aiming at exploitation of ocean resources rather than transport. It covers themes like oil and gas, fisheries, aquaculture, ocean wind energy, ocean mining etc.
- **The MESA project** (<http://www.waterborne-tp.org/index.php/mesa>) is an EU supported network action that will develop the background material for the next revision of the Waterborne TP documents. The most relevant deliverable from MESA in the context of CAT is “ICT Maritime Opportunities 2030, Maritime Connected and Automated Transport” that will be published by the end of August 2016.
- **Vessels for the Future** (<http://vftf.eu/>): This is an organisation of different industrial and research stakeholders developing new strategies for the shipping industry with a view towards establishing a potential public private partnership. . The scope is more restricted than what Waterborne-TP, but cooperation is close and VftF provides its expertise towards the WATERBORNE platform’s strategic R&I programming strategy.

In addition, there are numerous roadmaps with CAT relevance published by States and organisations with particular interests in the maritime transport sector. This includes national roadmaps in Norway⁴⁶ and the Netherlands⁴⁷ as well as companies such as DNV GL⁴⁸ and Lloyds Register⁴⁹. These roadmaps will normally be consistent with EU or organisational roadmaps mentioned above or developed specifically for objectives held by the respective nations or organisations. Thus, they are not discussed further here.

The waterborne sections in this paper are generally consistent with the main objectives in the national and organizational roadmaps as well as with Waterborne TP. The contribution from this roadmap is that it focuses specifically on the EU policy objectives. It is encouraging that the roadmaps generally mention the same high priority subjects, although there are some differences in how it is formulated and how the different solutions are prioritized.

3.3 *Research Gaps and Deployment Barriers*

Based on the *findings from the previous sections* on the state-of-the-art analysis, the *research gaps* and the *deployment barriers* to be overcome can be identified.

Findings on research gaps and implementation barriers (including e.g. access, costs, and business cases), which are *applicable across all modes*, include the following key points:

- **Technological development** for specific components and potentially including artificial intelligence (AI) to allow full autonomy under all circumstances.
- **Social acceptability**, including traffic safety, personal security, and privacy and protection from cybercrime in case of unmanned operation.
- **Regulatory frameworks** guaranteeing safe operation of unmanned systems and allowing a variety of innovative transport solutions.
- **Financial frameworks** for using public infrastructure and as a demand management instrument.

Other more *mode-specific findings on research gaps and implementation barriers* include the following:

Road Transport

The main actions to address *research gaps* that have been identified for road transport are:

- Development of resilient, robust and affordable sensors including multi-sensing components and (dynamic) out-of-vehicle sensors delivering functionality and performance for higher levels of automation (level3+);
- Handling of mixed traffic situations (interaction of vehicles with different levels of automation and different connectivity features (e.g. short range vs, long range), but also with vulnerable road users (cyclists, pedestrians) and other non-automated road users; and a common data platform for joint learning on mixed traffic and impacts on road/infrastructure design;

⁴⁶ See <http://www.maritim21.no/prognett-Maritim21/Forside/1254006265186> (In Norwegian)

⁴⁷ The Dutch Maritime Strategy 2015 – 2025, January 2015. Available from https://www.noordzeeloket.nl/images/The%20Dutch%20Maritime%20Strategy%202015-2025_4995.pdf

⁴⁸ See <https://www.dnvgl.com/technology-innovation/sri/index.html>

⁴⁹ See <http://www.lr.org/en/research-and-innovation/>

- European, shared framework for large-scale testing/piloting of connected and automated vehicle technologies and services in Europe (common methodologies for testing, impact assessment, data-sharing);
- Interaction with urban and regional development and transport strategies (esp. SUMP), potential synergies with other sectors (e.g. drastically reduced need for parking space), potential rebound effects. Scenarios need to be developed to involve a broader group of stakeholders – but as well to develop tools for a most efficient development.
- Evaluation methodologies of systems; evaluation methodologies for impact assessment of the introduction of Connected Automated Transport (CAT), and procedures and tools for the design validation, verification and performance assessment of CAT functions; as well as a virtual (digital) collaboration platforms for simulation along the value chain;
- Definition of (minimum) roadworthiness requirements of higher levels of automation aligned with UNECE and member state regulatory frameworks needs; technical and experimental assessment of minimum safety requirements to allow CAT on public roads (i.e. input for the Type approval process)
- New requirements of periodic motor vehicle inspections of CAT (based on the fact that the functionality of a vehicle will change during its lifetime due to software updates);
- Environmental perception (including highly accurate localisation/positioning) in complex and dynamic (urban) environments, combined with new components needed for removing effects of redundancy for actuation (for steering, braking, power-net and data transfer)⁵⁰;
- Extension, harmonisation and standardisation for C-ITS (systems connecting vehicles, road users and infrastructure); enabler for decentralised, complex, vehicle-user-infrastructure interactions and manoeuvres and trustworthiness and (cyber) security of C-ITS for automated transport. This needs to be in cooperation with the European automotive industry, as well as the digital and telecommunication industry.
- Driver attention and involvement (role, availability) in general within a specific function/ level of automation and specific in the context of transitions between the modes (levels of automation);
- Design and understanding of human centric vehicles and transport systems, safety systems enabling the freedom for “in car” productivity, entertainment, or other comfort, as well as safe and secure smart device coupling to the vehicle;
- Insight in necessary changes in infrastructure/traffic rules/traffic management
- Insight of benefits and optimised use of C-ITS technology and C-ITS generated data for urban traffic management;
- Research into and demonstration of the reliability, (functional) safety and robustness of connected and automated driving technology, concepts and components for redundancy for steering, braking and power net;
- Understanding user needs and social attitudes, to enable influencing the end user in the process of deployment and actual use of connected and automated vehicles; consideration of automation for a changing demographic (older users and today’s under 16 year olds who may not want/need their own vehicle);

⁵⁰ AMAA 2016, Highly automated driving - disruptive elements and consequences, Roland Galbas, Robert Bosch

- New business models for efficient, demand-specific deployment and use; specifically for CATS, addressing both economical as well as societal elements, and understanding of barriers for mass production of cooperative and automated driving systems;
- New training standards for appropriate use and maintenance of automated vehicles, including resistance to abuse and misuse; driver license needs in a mixed traffic environment;
- Connected and multimodal transport solutions for people and goods;
- Handling and potential use of the big data generated by C-ITS transport;
- Artificial intelligence to allow automated cars to act more similar to humans (complex perception and decision making, predictive driving), including moral dilemmas and related good practices also in relation to mixed traffic;
- Employment effects, including knock-on effects to current employment models of taxis, public and commercial transports, etc.
- Spatial impacts of CATS (land use, urban planning, design of roads, parking, etc.)

Relevant needs, beyond the direct research gaps, but related to *research and development* work:

- Need of a supportive regulatory framework (traffic rules, exemption frameworks and type approval (incl. harmonisation), liability, data traffic, cyber-security, on road beta-testing, etc.) that allows experimental research and benefits from its outputs, within European countries and across their borders;
- Allowance of testing and validations (pilots) on the public roads is needed to show the benefits and system achievements in real life as well as provide data driven decisions for industry and policy makers. The allowance is based on a national level, but should be more clear and shared amongst the Member States;
- Clear coordination between national and EU-initiatives to support innovation and deployment of smart mobility services and connected and automated vehicles.
- International standards for communication of information and intention between vehicles, their occupants and other road users.
- The end of roaming and the creation of the Single Digital Market should take into account road transport requirements and thus provide the framework for the boost of mobility applications and services.

Rail Transport

In case of rail transport, the main research gaps and the deployment barriers include:

- slow pace of implementation of European policy support measures and new standardized solutions
- a high number of national technical and operational rules
- focus on technical interoperability, without proper attention to operational interoperability, preserves the existing national operational rules and negatively impacts cross-border operation
- the relatively high CAPEX/ OPEX cost of rail-bounded system
- long life cycles of existing systems

- highly defragmented picture of railway regulations and (CAT) technical solutions among European countries
-
- 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
- weak relationship between general CAT developments, caused by policy trends, and the practical needs, foreseen benefits or existing constraints of customers
- weak inclusion of other rail-bounded modes (metro, tram) in the ongoing European research under Shift2Rail
- concerns about emerging cyber security and resilient communication aspects, which could slow down and higher the costs of the deployment of CAT solutions
- limited availability of COTS based solutions, as market is dominated by global industries offering specialized and expensive CAT products
- no vision on target architecture supporting soft and short term deployment of CAT solutions.
- various stages of development of automated rail solutions in various European countries
- expectation of new digital technologies, which could deliver breaking-through innovations to the railway sector, disturb organic developments
- insufficient number of skilled resources and lacking unification of training systems and technical culture
- culture of ex post coordination instead of ex ante cooperation

Air Transport

As already mentioned the research gaps for aviation are detailed in the ACARE aviation SRIA (see more details in section 3.2), which is currently undergoing an update process. Some research gaps identified in the SRIA are already being addressed in current research programmes and Joint Undertakings (e.g. SESAR, CleanSky) as underlined in section 3.1. It also has to be noted that CAT does not appear as a specific challenge for aviation but as a crosscutting theme and enabling technology in almost all research domains in aviation. CAT should in particular enable and contribute to:

- Flight and flow optimisation, monitoring and assessment of existing and future air vehicles.
- New operational concepts and new aviation services accommodating other vehicle missions and aerial applications, and enabling an efficient and agile system
- New concepts for information infrastructure, including the integration of Integrated Communications, Navigation, and Surveillance (ICNS), to address inter-modality and performance (safety, data capacity, quality of service, data security, cost-efficiency, interoperability, resilience, etc.). This will enable the provision of services that satisfy the needs of all air vehicle types and missions, together with system intelligence applications in mission management, air vehicle operations, air transport interface node operation, travel management and transport network management (for an intermodal transport system)
- Concept, systems, and interfaces for autonomous / automated operations.

For each of the above areas research gaps to be filled include notably in particular the management of safety & security threats induced by CAT from human to unmanned aviation, a change in terms of liability, environmental and economic impact and social factors (e.g. human factors including the level of

role/responsibility, change in the governance and, at the organisational level, education and training, social resistance)

As for any aviation system, CAT solutions should be developed in a way that ensures global airworthiness and interoperability of standards, fully synchronised with the development of technical solutions. However the current validation and certification frameworks are not adapted to the agility and new threats such technologies bring (notably security threats and new types of air vehicle). Furthermore appropriate legislative measures need to be developed to facilitate the provision of innovative and competitive CAT services to airspace users.

More general issues holding back the uptake of innovation include the following:

- ***Assurance and improvement of current extremely high safety levels*** requires detailed understanding of system interaction, human factor aspects, risk level assessment and mitigation options as well as verification of safety levels, which is a very thorough and time-consuming process
- ***Potential inadequacy of solutions with people's needs/expectation due to lack of people's engagement*** in the overall change process
- ***Lack of system point of view in the innovation chain***
- ***Lack of fast track*** options in the current ATM research framework programmes
- ***Lack of harmonisation and globalisation of certification.***
- ***Limited standardisation***
- ***Limited opportunities for social engagement*** although significant changes in society are to be expected
- ***Overall, lack of collaborative mind set in a fully privatised and highly competitive industry***

On the more specific aspects, the main barriers are the following:

- ***Aeronautical Spectrum deficiency***
- ***Reliance on systems from outside Europe***
- Difficulties in using cheaper, existing, compatible non-aviation industrial products (COTS)
- The balance between ***job creation and destruction*** cannot be assessed because of the lack of visibility over the level of automation that will ultimately be achieved and accepted
- The still-not-fully-addressed issues of ***dealing with a higher level of automation***, and more particularly contingency procedures that require immediate human intervention in the case of system failure, whilst the human was in a monitoring role before the event occurred.
- ***Regulation***, i.e. over regulation, under regulation, difference in regulation among the EU member states. Regulation (for current aviation) is certainly a barrier for drones uptake, and for good reasons i.e. to ensure the maintenance of the level of aviation safety that society expects. EASA is currently progressing on drone regulations, including geo-fencing, however
- ***Political will*** (e.g. intermodal transport, Single European Sky FABs)
- ***Lack of true FAB air-traffic centres*** or limited remote control towers
- ***Space infrastructure*** supporting all three aspects (automation, virtualisation and connectivity)
- ***Lack of appropriate virtual training/*** simulator centres

Waterborne Transport

In addition to the technical developments, regulatory, policy and societal issues are also important and require new solutions than what we have today. As an example, public acceptance of unmanned ship will in part depend on the public message from the European Community and other officials as well as the actual proof of the concept demonstrated to the public. Regulations are obviously in need of change, both for building and operating fully or partly unmanned ships.

Traffic management, more integration on the ship, more connectivity and reduced manning all have legislative requirements. Legislation will have to be established both for operator of ship (flag state) and for ports (port and coastal state) as well as for inland waterways (nationally or regionally). Traffic management, particular for sea going traffic, will be a challenge as this will have to include principles that are today in conflict with the freedom of the seas.

There are also issues related to liability in case of accidents that need policy and possibly legislative developments. There is also a need to support establishment of development and test infrastructure through simulators and dedicated physical locations.

The main *barriers to technical developments* that have been identified in the waterborne domain are:

- **Legislation** hinders deployment of more automated and autonomous vessels in local ports, nationally, regionally and internationally. Today, this is mostly legalisation that requires certain manning levels or specific competencies on board that are not relevant for automated vessels⁵¹. For international shipping, the main parties enforcing this is the flag state and the coastal/port state authorities. Most problems can be overcome by bilateral agreements between these, although this may require adjustments of national legislation. For inland waterways and coastal shipping, national legislation must be amended or there must be specific exceptions put in place. Existing national or local port byelaws may also hinder the use of unmanned or automated ships in ports unless the byelaws are changed.
- **Safety and evacuation of passengers on unmanned vessels** is today a completely unknown area. Current safety regimes relies on trained personnel being available to assist in emergencies. Unmanned short distance passenger only or car ferries in an interesting concept from a technical and economic perspective, but cannot be realized before the safety principles has been modified and legislation has been amended.
- **Business models** sometimes hinder development and installation of new and improved technical systems on waterborne vessels. This is typically because the cost of installation is born by the owner while the benefits are reaped by the manager or the charterer. There is a lack of mechanisms for risk and profit sharing. Similar mechanisms are also necessary to enable optimization of transport chains and the ship. This applies to owners and charterers of ships and to some degree ports and terminals and transport system operators.
- **Regulations on equipment** and integration on merchant ships hinders open innovation and by that development of new and innovative energy saving systems. Today's approval regime is very much based on testing and type approval of specific "boxes", e.g. an autopilot, a radar or an electronic chart unit and cannot easily accommodate new types of decision support systems that replaces parts of the traditional bridge equipment.

⁵¹ An analysis for deep sea can be found in section 4 of MUNIN deliverable D9.3 (footnote 22)

- ***Better and standardized physical integration*** with ports and other infrastructure is a prerequisite. This applies to cargo handling, shore power, automatic mooring, tugs and so on. This is a bigger concern for small ships than for larger as the relative port investment costs are much higher compared to the cost of the smaller vessels.
- It is unclear if the manufacturer of advanced automation and decision support systems can be made ***liable for accidents*** caused by failures in the system. This may hinder development of new and more automated systems.
- ***Uncertainty*** related to increased risk, fault recovery, new sensors and automated navigation can hinder development and deployment. It becomes very difficult to estimate return on development and installation investments until better data or risk control options are in place. Improved technology, risk assessment methods and legislation need to address these issues.

The main ***research gaps*** that have been identified in the waterborne domain are similar for seagoing traffic and for inland waterways. However, the specific technology will have to be adapted to the different waterborne sub-modes (inland, coastal, short sea, deep sea):

- Within ***ship automation***, the main technology gaps are the lack of open standards for integration between systems (integrated ship control) as well as for adding new and open innovation based products to the ship (open ship control). There is also a need to develop much better systems for technical maintenance of ship systems, including system monitoring and condition based maintenance planning. Today's maintenance systems for ships do not cover all technical systems and are mostly based on periodic maintenance, although condition monitoring systems are available for some systems.
- Technology gaps in ***ship autonomy*** are larger than for automation. One will need new sensor systems, including sensor fusion and object detection as well as automated voyage management systems for planning and executing the voyage. There will also be a need for remote control and shore control centre support, including accurate positioning systems for automatic or semi-automatic operations in congested waters such as docking and mooring.
- A specific problem is ***passenger safety on unmanned ships***. As noted above, unmanned short distance ferries is a very interesting concept, but requires new technology and routines to become viable.
- In ***traffic management***, additional functionality must be provided to the existing RIS (River Information Services) and VTS (Vessel Traffic Services) to improve safety and efficiency. Traffic management must be integrated into logistics systems to adapt just in time arrival to the commercial and operational requirements. This will require information on contractual arrival and departure times, port and cargo operations in addition to today's focus on maritime safety and security. One should also incorporate expected environmental conditions (weather, visibility) in the optimization of the voyage plan to avoid too late arrivals. Automated lock and bridge control for inland shipping should also be considered in future RIS systems. When ships start to use periodically unmanned operation and eventually develops into fully unmanned ships, this will have an impact on how traffic management must operate. One must also look at integration of pilot services for partly or fully unmanned ships.
- ***Integrated logistics systems*** need to be developed across modes and operations. It has already been identified as a main technological barrier in EU and significant research and policy developments are being aimed at solving the relevant issues. The main gap for the waterborne systems is to provide integration mechanisms in mode specific systems, such as the traffic management systems.

- **Digital connectivity** needs developments in cyber security and standardized data exchange protocols. It has to cover standardised data exchanges for ship operations, traffic management as well as for logistics and port operations planning. Standards in data exchanges on board ship and between ship and shore have a great potential for normal shipping operations. Cyber security is a very important factor in this domain: As more data exchanges takes place and as importance of the data increases, all aspects of cyber security can, if not addressed, cause a major safety or security hazard. This is a known problem in today's shipping, but needs further developments as digital connectivity increases in importance. One also needs to look into non-commercial data exchange systems for mandatory communication between vessels and authorities. VHF Data Exchange System (VDES)⁵² has been picked out for this function, but there are still more developments needed in this area.
- **Physical connectivity** is in general not part of CAT. However, the physical systems need to be integrated with the automation and autonomy support systems on the ship to optimize operations. As an example, automatic berthing can probably be much simplified if control of mooring system is integrated with the manoeuvring control algorithms. Currently, port regulations and infrastructure availability vary between ports. This should be harmonized, as standards in this area are important to achieve more automation. Transfer concepts are also needed to facilitate cross-modal transfer of passengers and cargo, and to facilitate vessel to vessel transfer (deep-sea to inland water & manned to unmanned).

⁵² ITU-R SG05 Recommendation to Plenary 1007, "Draft new Recommendation ITU-R M.[VDES] - Technical characteristics for a VHF data exchange system in the VHF maritime mobile band", 2015-08-28.

4. Strategic Implementation Plan

The *key output* of this roadmap document is the *strategic implementation plan*, where specific *research and innovation actions* and other policy support will be proposed. This plan will be summarised in a *table, in which the specific actions will be described* in view of the points below.

Types of action:

- Funding/ stimulation
- Networking/ governance/ coordination
- Regulation, guidelines and standards
- Awareness raising/ communication
- Research and innovation
- Market-based instruments and private financing schemes

Timeline:

- Short-term (2020)
- Medium-term (2030)
- Long-term (2050)

Sector or Responsible for implementing the action:

- public sector (local/regional, national, European level)
- Role of the private Sector Roles
- Role of other players (e.g. NGOs, intergovernmental organisations, etc.)

Priority of action:

- Low priority
- Medium priority
- High priority

Cross Modal and Horizontal Actions:

<i>Description of Action</i>	<i>Type of Action</i>	<i>Sector</i>	<i>Timescale</i>	<i>Priority</i>
Customer-centric, Intermodal Integrated Transport System:				
Develop new customer-centric, inter-modal integrated mobility system concepts, infrastructure and metrics	R&I	Priv+Pub	Medium	High
Develop a customer-centric, intermodal integrated Transport Policy (incl. e.g. harmonized passenger rights)	Regulation	Pub	Medium	High
Develop an architecture view incl. interoperability schemes for the customer-centric, inter-modal integrated	R&I	Priv+Pub	Medium	High
Develop transport revenue sharing models and trusted information transparency systems to support it.	R&I	Priv+Pub	Short	High
CAT in a Multimodal Integrated Transport System:				
Cybersecurity				
Design, develop and validate an Integrated and Intermodal Transport Architecture resistant to CAT specific threats (e.g. cybersecurity threats)	R&I	Priv	Medium	High
Develop and validate generic tools and procedures to monitor, assess and mitigate cyber threats at transport level taking due account of mode specificities	Regulations Standards	Priv+Pub	Short	High
Develop privacy regulatory framework to cope with CAT applications	R&I	Priv	Medium	High
Hybrid Vehicles				
Develop and validate concepts and standards for a global and multimodal interoperability of hybrid vehicles covering more than one mode	Regulations Standards	Priv+Pub	Medium	Medium
Develop and validate new concepts and standards of interchange locations to cope with hybrid vehicles and multimodal journey	R&I	Priv+Pub	Medium	Medium
Data Sharing				
Develop infrastructure for sharing transport operating data, incl. governance framework (SWIM for transport)	Regulations Standards	Priv+Pub	Short	High
Develop, validate and exploit transport wide data intelligence for an integrated, resilient and low-carbon system taking due account of mode specificities	R&I	Pub+priv	Medium	High
Develop and validate multimodal contingency plans in a multimodal integrated transport system	R&I	Pub+priv	Long	High
Resources				
Develop new skills, education programmes, training requirements, and facilities to cope with CAT application specificities, notably the change in dynamics and the change in roles and responsibilities	R&I Regulations Standards	Pub+priv	Short	High
Social Factors				
Develop methods for the management of nuisances linked to CAT developments, especially in urban areas	R&I Regulations Standards	Priv+Pub	Medium	High
Understand and manage people's expectations, behaviours, and, cultures	R&I	Priv+Pub	Short	High
Awareness campaigns and large scale demonstrations to increase people's acceptance of connected and automated vehicles (including hybrid ones – all modes)	R&I Policy	Priv+Pub	Medium	High
Develop risk acceptance criteria for use of autonomous vehicles in public spaces.	R&I Policy	Public	Short	High

Customer-centric, Intermodal Integrated Transport System:

The development of CAT services in the context of a future customer-centric, inter-modal integrated mobility system requires that such system exist. However since the publication of the Transport White paper and Flight path objective on transport inter-modality actions, very little progress has been made.

Prerequisite actions common to the seven STRIA roadmaps must be developed in particular those which would orchestrate the development of a coordinated approach to its realisation. They include notably the development of well-defined policy, the architecture of such system including the interfaces between modes in the areas of vehicles, traffic management, infrastructure but also performance criteria and associated metrics. Moreover, legal and competitive issues related to intermodal transportation contracts between the passengers and the transport companies should be clearly defined.

Single mode transport programmes based primarily on mode specific expertise are not appropriate for tackling the development of an intermodal and integrated European transport system. There is therefore a need to develop cross-modal ventures to address common issues, the in-sector issues are to be dealt with by the existing or to be created private/public entities.

CAT in a Multimodal Integrated Transport System:

Common issues to transport modes in terms of CAT services have been identified in the areas of cyber-security, data sharing, resources and social factors. They should be addressed in a generic view nevertheless there will always remain some specific component to fully address the need of each individual mode. Those are captured in the mode specific tables.

On the other hand some mode specific developments could be developed in a broader context. For example the Aviation's System-Wide Information Management system (SWIM) could be integrated with similar systems of other modes.

Additionally hybrid vehicles with high potential for innovative mobility services are by essence not mode specific but certainly need further attention in terms of R&I, standards, and regulations.

4.1 Road Transport

The research and innovation actions for road transport can be broken down into three main categories, as main objectives to be achieved:

- successful technological development (A)
- swift adaptation of CAT technology (B)
- ensure an attractive Europe (for citizens, industry and innovation) (C)

In the table below, the research and innovation actions and recommendations are ordered in these groups. The more detailed information below the table is in the same order. It should be noted, that the following information should not be read like the activities are starting from scratch.

They should be seen in coherence with other ongoing activities, with a slightly different focus. The focus here is the R&D need, the C-ITS platform focusses on the deployment issues, while GEAR 2030 focusses on the policy options and the Oettinger roundtable discussions focus on the more legislative and harmonization parts. The table below feeds into those initiatives as well.

<i>Description of Action</i>	<i>Type of Action</i>	<i>Sector</i>	<i>Timescale</i>	<i>Priority</i>
Successful technological development (A)				
A1. Develop resilient, affordable sensors and CAV technology operational in all weather and harsh environmental conditions	R&I	Industry and RTO	Short	High
A2. Define (minimum) roadworthiness requirements of higher levels of automation	R&I + Regulation, guidelines	Industry, RTO and EC	Short	High
A3. Improve detection technology and perception intelligence	R&I, Market based instruments	Industry, RTO	Short	Medium
A4. Identify essential changes in infrastructure, traffic rules and traffic management, define the existing gaps and technological developments	R&I + Regulation, guidelines	Industry, RTO and EC	Short	Medium
A5. Develop ways to enable use of big data in (road) transport for (city) traffic management	R&I, Market based instruments	EC, Industry, local governments	Medium	High
A6. Define the needs, risks and solutions of the ICT side of CAT, including the ICT infrastructure and cybersecurity, and develop the related solutions to cover the current gaps and risks	R&I	Industry, RTO and EC	Short	High
A7. Develop AI for road vehicles	R&I	Industry, RTO and EC	Long	Medium
Swift adaptation of CAT technology (B)				
B1. Develop and incorporate mixed traffic solutions	R&I	Industry and RTO	Medium	High
B2. Develop a European testing framework, first steps to deployment	R&I + Regulation, guidelines	Industry, RTO and EC	Short	High
B3. Develop and agree on evaluation methodologies for systems and vehicles	R&I + Regulation, guidelines	Industry, RTO and EC	Short	High
B4. Develop a common framework for regulation and standardisation	R&I + Regulation, guidelines	Industry, RTO and EC	Medium	High
B5. Create understanding and acceptance for the CAT technologies, including improved driver training, driver acceptance and societal acceptance	R&I	EC	Medium	High
B6. Demonstrate the reliability, safety and robustness of CAT	R&I + Awareness raising + Funding, stimulation	Industry, RTO and EC	Medium	High
B7. Enable user understanding and influence technology uptake by users, create a technology pull by cities by giving them a more central role	R&I + Awareness raising + Funding, stimulation	Industry, RTO, local governments and EC	Medium	Medium
B8. Develop strategies for transport demand management	R&I, policy	RTO, EC, local governments	Medium	High
Ensure an attractive Europe (C)				
C1. Create the future workforce for European CAT developments, with all critical capabilities represented	Policy, R&I	EC, local governments	Short	High
C2. Develop new business models for widespread deployment	R&I, Market instruments	Industry, RTO and EC	Medium	Medium
C3. Investigate the potential effects of road automation on European employment and competitiveness	R&I, Awareness raising, Funding and stimulation	Industry, RTO and EC	Short	High
C4. Identify barriers for mass production of CAT, as well as recommendations to overcome the barriers. Define how to bridge the valley of death between TRL 7 and TRL 9.	R&I	Industry	Short	High
C5. Focus on enabling use of automation/connected mobility for environmental friendly transport	R&I, policy	Industry, RTO and EC	Short	High
C6. Gather all stakeholders in CAT to improve the discussion, information exchange, in and beyond Europe	Policy	Industry, RTO and EC	Short	High
C7. Spatial impact due to CAVs (land use, use of parking, city layout, etc.)	R&I, Policy	Member States, EC	Medium	Medium

The more detailed research and innovation actions for road transport are described below.

Successful technological development (A)

- A1. Develop resilient, affordable sensors and CAT technology operational in all weather and harsh environmental conditions: facilitate the development of sensor technologies resilient to different weather conditions and operational in variable road environments. With the introduction of CAVs on SAE level 3+, requirements on sensor functionality and performance increase substantially.
- A2. Define (minimum) roadworthiness requirements of higher levels of automation; provide knowledge on the length of time required for roadworthiness testing of automated vehicle after its first use, at what rate and by which authority.
- A3. Improve detection technology and perception intelligence; though many technological solutions are developed, the step towards affordable detection technology is to be made. Part of this step will be the optimised, multi-purpose use of sensor technology in vehicles, which leads to challenges in sensor integration and sensor fusion of different data sources. Key issues are the sensor technology's functional safety, reliability and fault tolerance, but also for the full vehicle system. Consider also its resistance to hacking and implications for security.
- A4. Identify essential changes in infrastructure, traffic rules and traffic management; so far it is not clear what challenges connected and automated vehicles pose to the infrastructure, and how improved infrastructure can boost the uptake of automated driving. Primary focus should be on truck platooning, followed by urban challenges.
- A5. Develop ways to enhance the optimised use of big data in (road) transport for (city) traffic management and start implementing new traffic controls for optimised traffic flow (in cities). This should be a technology development that can be enrolled throughout many European cities without large adjustments per city. It should consider how to maximise the impact of smart and safe mobility solutions, and stay ahead in the race for global competitiveness for digitalisation and connectivity of vehicles. The take up of this challenge will have a strong effect, not only on the automotive industry, but also on other related industries. Also, work on Road Environment information, i.e. demonstrate high accuracy real-time exchange of highway or urban road environment information including pedestrians, cyclists, etc.

- A6. Enable optimised use of new ICT technologies (Internet of Things/Wearables, Digitalisation, Big data, data analytics and visualisation, Cloud computing, Connectivity, Deep Learning) to support the performance of automated transport technologies, following a multidisciplinary approach that involves all relevant stakeholders combining the vehicles, telecommunication and infrastructure industries, and also considering the roles and responsibilities of the public and private entities:
 - IoT/ Work on Data chain:
 - Mechanisms to share vehicle sensor data in an automotive IoT environment
 - Mechanisms to guarantee reliability, accuracy, veracity, integrity, etc of data sources
 - Novel security mechanisms – authentication, authorisation & encryption
 - Work on Data transmissions
 - Dimension and simulate data connectivity of AVs for high penetration scenarios; Derive requirements for 2025-2030 mobile evolution
 - Demonstrate 5G capabilities in highly congested roads
 - Work on data computing
 - Proof-of-concept, demonstrate and evolve Edge computing techniques for AV to support AV in challenging situations such as highly congested highways or intersections
 - Big data (analytics and visualisation techniques, latency, fast processing and decentralised data handling)
 - Cloud computing
 - Connectivity (coverage, spectrum, interoperability and standardisation, most efficient use of 4G, 5G, satellite, ITS-G5,).
 - Work on vehicle architecture
 - Novel vehicle architecture for Automated functions
 - Resilient vehicles: Fail-safe – fail operational hardware and software
 - Integrated AV management solutions maximizing safety, traffic efficiency, environment impact – what are the optimum?

This should also include the optimisation of computing power for perception and cognition as well as the high performance ability for data services. Cyber-security and privacy protection include the emerging use and handling of big data, back office challenges and demands to be put to the wireless communication system such as time-critical and safety-critical applications. This should include development of secure and safe system architectures. Furthermore, focus should be on cyber security. Any solution should therefore consider the whole vehicle lifecycle. Further, the residual risk (remaining risk after consideration of all security measures) need to be properly addressed to guarantee safe operation, as well as measures to secure connected and automated vehicles from manipulation and threats to guarantee safe operation and protection of goods.

- A7. Develop AI (including Deep learning) for road vehicles; as the engagement of humans in the driving task is reduced, moral and ethical aspects of driving need to be controlled by more advanced AI.
 - Prepare AV in view of the evolution of the computing power – what if computing power of a brain costs 1000\$ by 2029? (See Ray Kurzweil)
 - Establish a European repository of driving scenarios for deep learning – an open data base with millions of km of road scenarios to train and learn from, to test and evaluate, to design and program new functions.
 - Advance specific deep learning techniques for driving scenarios based on combination of video, laser, radar data

Swift adaptation of CAT technology (B)

- B1. Develop and incorporate mixed traffic solutions: Understand how different levels of automation in vehicles affect matters such as road safety and traffic flow, in a mixed traffic environment with older, manually controlled vehicles as well as “non-vehicles”, e.g. bikes, pedestrians (VRUs, Vulnerable Road Users) etc. This will be highly influencing the length and severity of the so-called transition phase, during which the level of automation as well as the number of (partially) automated and connected vehicles on the public roads is increasing, ultimately until full connectivity and automation. The interaction between a larger share of automated and non-automated cars, eventually in the same physical space, (especially in urban areas where there will also be the interaction with (unconnected) vulnerable road users such as cyclists and pedestrians) bears a lot of potential conflicts that can limit the exploitation of the advantages of automated transport. Automated / autonomous vehicles are by definition defensive and are programmed to stop when “obstacles” like crossing pedestrians are detected. In increasing transport volumes and mixed traffic situations, such programming may lead to a severe reduction of the capacity of current traffic.
- B2. Develop a European large scale testing framework:
 - Include testing and validation on different road categories, and develop a common methodology for conducting and evaluating Field Operational Tests (FOTs) on CAT systems. Use FOTs to understand road user and driver behaviour, traffic flow, road safety and energy consumption for automated and mixed traffic for passenger cars, trucks and urban transport systems. The FOTs should be followed by large-scale, cross-border European deployment projects for connected and highly automated driving, following the same framework.
 - Large-scale, cross-border deployment and implementation projects for connected and automated driving (level 4). Testing must include connectivity: e.g. V2V, V2I communication/ Internet of Things/ connection of AV with traffic management systems and cloud-based services. The projects should explicitly include multi-modal urban mobility systems, including wide use of highly automated mobility on demand services.
 - Testing framework focussed on CAT for freight solutions should enable the European logistics sector to make a leap forward, while on the other hand also the (in)direct benefits of CAT solutions on efficiency and emission reduction can be qualified.
- B3. Develop and agree on evaluation methodologies for systems and vehicles; to enable deployment of CAT systems over (and beyond) Europe, a common understanding of the safety, reliability and security of connected and automated vehicles is essential. A method like the EuroNCAP may be considered, for instance. This should include evaluation of fail-safe/fault tolerant system achievements, as well as evaluations of safe operation in complex and mixed traffic situations. Virtual testing and certification with the ever-increasing calculation power might provide a suitable solution. Additional work on vehicle software evaluation:
 - New vehicle testing/evaluation programme through software testing approaches (complementary to Type Approval)
 - Low-cost methods to measure safety and reliability performance and effectiveness of vehicles
 - Create an Over-the-air update software approval process (virtual type approval)
 - Rapid AV software incremental design techniques integrating OTA update principle (what are the implication of OTA on the SW design; what are the novel programming techniques that guarantee that a change in a part of the SW will not require a full SW approval process)

- B4. Develop a common framework for harmonisation and standardisation; which should include cross border and global issues, such as consideration of appropriate infrastructure and communication, applications and safety functions, as well as regulation guidelines. Based on this research, the EC and Member States will have to enrol the harmonisation and standardisation, preferably in cooperation with non-European entities from Japan and the US, using the running activities on trilateral cooperation. This framework should be valid not only for new vehicles or systems, but also for system updates.
- B5. Improve system understanding, use and acceptance by the human driver; there is a need to understand driver attention and involvement in driving and other non-driving related tasks, and how this affects road safety. Attention should be given to training needs and skills degradation as use of automation increases as well as how a mixture of automated and manual vehicles affect traffic management and road safety. The value and barriers of automation to different demographics, such as older drivers with cognitive impairments or younger, technology-savvy, users need further thought. Furthermore, it is essential to not only pay attention to the user acceptance, but also to public participation and societal acceptance, like when a CAT driven car would kill a person. It is unclear yet, if unmanned freight transport would be easier accepted than unmanned passenger transport. So far, focus is on either highway solutions and impacts, or on urban scenarios. In the next steps, also the effects and uptake for remote and/or rural situations should explicitly be included. Work on Drivers AV adoption, learning and trust, including
 - Design while-driving driver education programmes (training by driving)
 - Design new resilient Driver interaction detecting drivers misuse and abuse with high acceptance
- B6. Demonstrate the reliability, safety and robustness of CAT; system reliability and system safety including software safety. International FOTs can be used to show the fail-safe and fault tolerant functioning in varying, mixed traffic conditions, including multi-brand, highway and urban situations.
- B7. Cities can play a key role in the active uptake of the new technologies. Cities should be helped to get prepared to do so; a better understanding is needed of their needs, and how they can actively benefit from investing in (projects related to) CAT. They thus can also help to boost the understanding of end users, of the benefits and needs of these technologies, by showing the added value in urban mobility. To make cities aware of this, first a better understanding is needed of their current knowledge position, and their needs to actively participate in projects and in investment programmes. Their knowledge and needs need to be clarified. The lack of applicable knowledge already emerges from the absolute lack of CAT mentioned in the SUMP (Sustainable Urban Mobility Plans). Valorisation of urban transport data should be included in the discussions with cities. Improve system understanding, use and acceptance by the human driver; there is a need to understand driver attention and involvement in driving and other non-driving related tasks, and how this affects road safety. Attention should be given to training needs and skills degradation as use of automation increases as well as how a mixture of automated and manual vehicles affect traffic management and road safety. The value and barriers of automation to different demographics, such as older drivers with cognitive impairments or younger, technology-savvy, users need further thought. Furthermore, so far, transport modelling assumes a relatively constant travel time budget. What if the time to cover the distance is no longer perceived as travel time – but e.g. as relaxing or working time? It is unknown so far, what impacts on land use patterns would be. Vehicle automation to support an aging population should be a key implementation scenario, to be prioritised by government and local authorities in terms of R&D efforts and bringing to the market in terms of specific targeted services.
- B8. Strategies for transport demand management should help to avoid an enormous boost of transport demand, once transport of people and goods would be highly automated and easily

accessible to all European citizens and companies. An unmanaged growth will destroy any potential efficiency benefit of CAT technologies, eventually leading to a collapse of the transport system. Instruments to manage the transport demand on local, national and European level are needed, incorporating transport of people and goods.

Ensure an attractive Europe (for citizens, industry and innovation) (C)

- C1. It is deemed essential for an attractive European CAT industry, and an independent role of the European industry (both production and the knowledge industry) to pro-actively work on the future's work force. Data experts, mechanical engineers, experts on system development, ICT, software etc. will be needed in vast amounts. This can be initiated by creating a very firm link to universities. The creation of competence centres (across modes) could help, also challenges for university students "to be the best in our field" and to stay in our field (like annual challenges in which university teams compete in creating new CAT developments, in close connection to the industry).
- C2. Develop new business models for widespread deployment; including car-sharing models and models for the mixed use of private and public vehicles. These models should also include new actors entering the field and the influence of disruptive developments should also be taken into account. Such business models will help the European industry face the challenges related to the market introduction and market uptake of connected and automated vehicles.
- C3. Investigate the potential effects of road automation on European employment and competitiveness; continued investment in the manufacturing sector of systems for CAT, such as radars, cameras and sensors. Opportunities for training and transfer of knowledge in development of CAT-relevant technology. Encourage integrated European stakeholder support for activities such as innovative automation in restricted areas.
- C4. Identify barriers for mass production of CAT, as well as recommendations to overcome the barriers; this is very important to ensure a competitive role for the European industries, coming originally from the automotive industry or e.g. the data industry. A critical factor will include an understanding of how to encourage mass production of transport system components at globally competitive costs, whilst still ensuring a safe and decarbonised transport system.
- C5. Focus on enabling optimised use of CAT for environmentally friendly transport, investigate opportunities for encouraging ride-sharing trends and services, increasing uptake by demonstrating its benefits. Solutions for more environmentally friendly fuels and charging opportunities.
- C6. Gather all stakeholders in CAT to improve the discussion, information exchange, in and beyond Europe; establish structured high level dialogue/ stakeholder platform on CAT to: facilitate the exchange of experiences and best practices in MS and between MS; discuss developments of CAT in Europe and worldwide via for a such as the tri- and bi-lateral working groups. This should also explicitly include:
 - Support cities and regions to prepare for the integration of connected and automated vehicles into a wider transport system concept. The aim must be to optimize the transport network and to maximize the impacts of energy efficiency and road safety.
 - Putting in place the required digital infrastructure networks allowing fast and secure connections between vehicles and traffic management systems
 - Develop solutions to capture and exploit data in order to improve transport networks and understand how people interact with transport systems in the city
 - Consider how road or cloud-based technology can be used for CAT

Additional *supporting policy options* may include the following:

- Address important standardization, legal and regulatory issues (e.g. regarding deployment, testing, road and traffic rules, data protection and sharing, privacy, liability, cyber-security, etc.) which prevent the deployment of innovative automated transport technologies. These issues will be covered in the GEAR 2030 initiative and will therefore not be covered further, here.
- Explore, together with the national authorities of those Member States interested in testing automated vehicle technologies, the introduction of temporary permits for testing. The idea is to grant innovative solutions with the appropriate framework for their real-life testing and demonstration in certain geographical areas, even if not all procedures or requirements of legislation in force are complied with.
- Support international cooperation. The EC should further encourage the cooperation or “twinning” of EU-funded projects with entities participating in projects funded by programmes from other parts of the world (in particular from the US and Japan) to exchange knowledge and experience and exploit synergies. Ongoing cooperation activities, such as the Tri-lateral working group on Road automation should be continued.
- Encourage cooperation between policy makers, technology-developers and standards organisations to form agreements for uniform development of communication and positioning technologies, formats and interfaces for data exchange, human-machine interfaces, aspects of maintenance and technical inspection.
- Create a coherent funding policy for automated and connected transport which includes national, multi-national (like EUREKA) and European levels. Assess the possibility to use new funding instruments like an Important Project of Common Interest.
- Support close cooperation between Member States to avoid fragmented frameworks for the development, testing and deployment of connected and automated driving technologies across the different European Member States.
- The European Commission should support the developing of tools for an effective ‘learning by doing’ approach, as is currently established in the FESTA-framework allowing results from FOT’s to be published and exchanged. However, uptake requires this information to be easily accessible and consequently be used by other companies and in other testing situations. Especially, if lots of information and data is put available, it will become increasingly harder to find what is relevant and useful for the next step. To overcome this problem, a solution might be to have a NCAP-like organization to support the industry by providing relevant data and information of previous tests, and afterwards – by request – checking if companies have used to available data and information in the development or improvement of their own solutions and services.

Particular points regarding the *transition phase*:

- Whereas a ‘final stage’ with automated vehicles only is easily imaginable, the interaction between a larger share of automated and non-automated cars in urban areas bears a lot of potential conflicts that will limit the exploitation of the advantages of automated transport.
- We need to explore how a transition phase could work and what the limitations are. An answer needs to be given to the fundamental question: Will there be a need to restrict the use of not-automated cars in certain areas (or certain times)?

Interaction with *non-motorised road users* / impacts on *urban street design*:

- Automated / autonomous cars are by definition defensive and are programmed to stop when “obstacles” like crossing pedestrians occur. Assuming strongly increasing transport volumes, such programming may lead to a severe reduction of the capacity of current traffic. What are the ways to deal with these conflicts?
- Will major streets become segregated, elevated, fenced etc. to avoid disruptions of the traffic flow? What are potential impacts on the design of road infrastructure / public space?
- Are other communication instruments thinkable between non-motorised road users (and their disruptive behaviour) and automated vehicles?

Specific instruments of *demand management*:

- We can expect a substantial growth in traffic volumes that may overcompensate the gains in efficiency. Even a collapse of the transport system is thinkable. Some recent studies show that high-capacity collective transport and demand responsive flexible smaller collective systems will be necessary.
- What are appropriate instruments to incentivise the use of collective (automated) transport modes vs. the ‘autonomous taxi’ – that may offer a much more convenient door-to-door trip? What are the instruments of demand management on the local and on the national level?

New *behavioural patterns* and interaction with *land-use patterns*:

- So far, transport modelling assumes a relatively constant travel time budget. What if the time to cover the distance is no longer perceived as travel time – but e.g. as relaxing or working time? Can we expect impacts on land use patterns, esp. more sprawl – thus also more transport impacts?

4.2 Rail Transport

The following table presents a list of actions for the rail transport. This list takes into account the objectives of the Strategic Rail Research Innovation Agenda (SRRIA) and related ERRAC roadmaps. However, to reach the technology goals and overcome barriers, the list also refers to actions for a better sharing of experiences and best practices and to robust solutions on interfaces with other modes of transport. Links to CBTC solutions should also enable a better incorporation into R&I efforts of other types of rail bounded transport (e.g. metro systems), not included in ongoing Shift2Rail programme. Although some of the specified actions can be found in the Shift2Rail multiannual plan, the STRIA refers to higher Technology Readiness Levels (TRL).

<i>Description of Action</i>	<i>Type of Action</i>	<i>Sector</i>	<i>Timescale</i>	<i>Priority</i>
Develop a common policy framework with other transport modes to share experiences and best practices of using CAT technologies within and among various transport modes	R&I	EC ⁵³	Medium term	Medium
Develop and deploy new IP based communication system for railways	R&I	EC,	Short term	High
Define optimal transition roadmap for applying CAT technologies, taking into account operational aspects of mixed traffic situations	R&I	EC, rail sector	Medium term	High
Develop a common framework for technical harmonisation and standardisation between (ERTMS/ CBTC), TMS and other parts of overall signalling system (e.g. interlockings)	R&I	EC, Industry rail sector	Medium-term	Medium
Develop a common framework for operational harmonisation and standardisation (ERTMS/ CBTC) for automated railways including degraded modes scenarios	R&I	EC, rail sector	Long-term	Medium
Develop and deploy new IP based communication system for railways; together with the strategy for the future technological developments of communication systems	R&I	EC,	Short term	High
Develop a common framework for the application of higher GoA levels (3/4) in various market segments of railway domain, including related technologies, e.g. moving block	R&I	EC, rail sector	Short-term	High
Develop detection technology and perception intelligence for ATO operations in the ERTMS/ETCS mode (cross fertilization with the road transport)	R&I	EC, rail sector	Short term	Medium
Develop unified testing & approval procedures for interoperable CAT applications with safety relevant functionalities	R&I	EC, Industry	Short-term	High
Support the development of new COTS for a better connectivity of trains, infrastructure elements and their smart controlling, measuring and monitoring devices based on Internet of Things (IoT) with ensuring proper safety and lower life-cycle costs	R&I	EC, other sectors	Long-term	Medium
Improve rail system resilience against cyber and physical attacks	R&I	EC, Industry, rail sector	Short-term	High
Improve and develop the use of 'big data' in order to improve rail system maintenance and operation	R&I	Industry	Medium-term	Medium
Develop a common framework for future automated maintenance techniques of rail infrastructure and rolling stock embedded in overall asset management system	R&I	EC, rail sector	Short-term	High
Develop the ability to manage obstacle detection in front of running trains	R&I	EC,	Short-term	High
Enable the fast implementation of solutions for supporting / realising energy efficient driving using information from TMS	R&I	EC,	Short-term	High
Develop solutions a framework for managing train integrity specifically for freight trains	R&I	EC,	Short-term	High
Support the development of hybridized on-board, safety relevant solutions for train positioning based on GNSS and other technologies and its reporting	R&I	EC, other sector	Short-term	High

⁵³ EC is the funding authority, Shift2Rail is responsible for R&I activities

The above recommended actions include the following groups of issues:

- Policy measures towards a better interconnectivity among various transport modes, offering robust solutions for last mile.
- Increased modularisation for CAT applications used in various types of rail bounded transport (example - ERTMS and CBTC), which should enable inclusion of e.g. metro solutions in the R&I agenda
- Higher Grade of Automation (GoA) levels: To realise the strategic objectives the R&D activities will aim at the evolution of higher levels of automation (up to GoA3/4) by implementing the Automatic Train Operation (ATO) in all rail market segments (high speed, mainline, urban, regional, and also freight lines). ATO operation will enable further increase of safety, as well improvements of operational and energy efficiencies. It will primarily be developed for the ERTMS/ETCS environment. Supply industry and railways will have to consolidate efforts towards the development and seamless deployment of a new, adaptable and IP based communication system, as one of building blocks of the future UTCS – Universal Train Control System. The UTCS will have to be a cost-effective solution that can be easily introduced for for all rail market segments, which will be based on ATO and moving block principles and be well connected to modern and, as far as relevant existing, traffic management systems. Enablers and blockers of automation should be assessed.
- Intelligent systems supporting operation: The use of satellite positioning and smart, radio-connected intelligent wayside objects as well as the development of a modern train integrity solution will move towards achieving deployment stage and will make feasible cheaper operations costs. They will further facilitate maintenance efforts, improve operational efficiencies and open new functional possibilities for railway network information management and control. The adoption of Driver Advisory Systems will reduce energy consumption while reducing headways will increase capacity.
- A strategy for future-proof communication systems, with as a first step, deployment of IP based systems.
- The development and increased adoption of automatic and/or decision support systems, not only for operational purposes, can optimise the efficiency of resources usage such as infrastructure, rolling stock, crew and traction energy lowering the overall costs. It will be necessary to manage the transition to complete automation and resilience, safety, security and cyber security while allowing the right degree of accessibility
- Intelligent systems for freight: Within the rail freight sector the development and deployment of modern solutions for automatic coupling of wagons and automation progress in terminals and marshalling yards will be needed to increase speed of handling on a last mile and to contribute to rail competitiveness.
- Automated testing: Higher automation in rail transport will require unified approval procedures, common operational rules and improved automation of testing processes.
- Intelligent, data driven measurement and monitoring: New generation Train Control and Monitoring systems will be data driven to help increasing reliability levels of railway traffic. This will have to be supplemented by smart systems to measure and monitor the status of all railway assets and allow mapping and optimising energy flows within the entire railway system. Fostering the next step from prediction to artificial intelligence (Big Data). The development of global automatic train supervision can help the overall operation efficiency (e.g. control of track adherence, real time rerouting of trains in degraded situation...)

- Intelligent stations: Improving customer experience at stations will be achieved by development of solutions to improve accessibility, capacity and security for passengers as well as the interconnection with other (automated) modes. These solutions incorporate intelligent measuring and monitoring systems and various IT solutions. The importance of the relationship between accessibility and security will increase in time.
- Cooperation with road to further improve safety at level crossing through more automation in rail (e.g. obstacle detection) and road (e.g. information to driver, automatic brake of vehicle).
- Cross modal integration/interoperability: Foster the next step of integration. Freight Rail 4.0 – Industry 4.0; Waterborne 4.0- Port Terminals- Freight Rail 4.0; Mobility 4.0 – Smart City (including Urban Transport).
- New autonomous, self-propelling rail freight wagons.
- Societal aspects: Increased automation and connectivity will have impact on the level of employees within rail-bounded transport. ATO deployment will limit the number of train drivers, while impacting current maintenance organisation. Intelligent wayside and on-board measuring and monitoring systems will require less maintenance staff. Intelligent solutions at stations, a different way of dealing with ticketing systems, security issues, etc. would lower demand on related staff. On the other hand in all ATO levels the accessibility aspect shall carefully be analysed.
- The social perception and acceptance of automation should be considered in the transition period to higher adoption rates. This negative social impact should be considered from early stages of the further deployment of automation and connectivity. Moreover, limits on connectivity, due to EMC aspects and impact on health should be added as a research topic.
- Tackle the challenge of using big data to provide adequate information to customers and train operating companies to improve their choices (i.e. predictive maintenance, provide services based on customer needs). Manage the transition from data to information and from predictive to prescriptive analytics. Promote systems integration and interoperability framework. Big data, open data, privacy issues, Integration of Artificial Intelligence and Cloud computing should be considered/addressed. Safety and environmental issues are important factors for the modal share in railways. Actions should promote satisfactory levels for both.

4.3 Air Transport

Considering the five Flight Path 2050 challenges for aviation, R&I actions in the aviation domain regarding CAT developments are listed in the table below. The list is not complete but presents the subset of the most relevant actions which would lead to a successful deployment of highly competitive low-carbon CAT solutions in air transport.

These areas of activity fall outside the current Clean Sky and SESAR programmes which have their own agendas. In fact the “Pilot Common Projects” implementation regulation (EU) No 716/2014 already specifies which ATM solutions will be deployed by 2024.

The European ATM Master Plan also provides the detailed view of the deployment of SESAR solutions towards the realisation of the SESAR vision. Full deployment is targeted between 2035 and 2040. Additionally the industry will progressively be introducing worldwide air vehicle improvements developed through the Clean Sky programme.

<i>Description of Action</i>	<i>Type of Action</i>	<i>Sector</i>	<i>Timescale</i>	<i>Priority</i>
Social and market needs in a competitive global environment				
Develop CAT solutions in support of new operational air-transport concepts accommodating all existing and future vehicle missions	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>Medium</i>
Develop, validate and standardise new concepts for information sharing infrastructure, fully interoperable with other transport modes.	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>High</i>
Develop and validate autonomous/automated/virtualised concepts, systems, interface and operations	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>High</i>
Develop certification framework including validation tools for autonomous air and hybrid vehicles which include an air component	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>High</i>
Develop and test new air or hybrid-mode business model concepts with economic benefit to rural or remote areas	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>Medium</i>
Develop a European traffic management system for the drone sector	<i>R&I Standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>Urgent</i>
Develop future concepts of air flow management (composed of mixed levels of autonomy) in a 2050 transport context	<i>R&I</i>	<i>Priv+Pub</i>	<i>Long</i>	<i>Medium</i>
Set up a R&I framework adapted to the rapid-change dynamics of CAT products and their security threats	<i>Policy</i>	<i>Pub</i>	<i>Short</i>	<i>High</i>
Develop a regulatory framework to support competitive low-carbon CAT solutions	<i>Regulation</i>	<i>Pub</i>	<i>Short</i>	<i>High</i>
Develop a regulatory framework to address changes to air transport-specific liability and insurance principles given higher levels of autonomy	<i>Regulation</i>	<i>Pub</i>	<i>Short</i>	<i>High</i>
Develop metrics and tools to quantify insurance risks of autonomous aircraft	<i>R&I</i>	<i>Priv</i>	<i>Medium</i>	<i>Medium</i>
Develop and validate highly rationalised-spectrum-efficient CAT solutions	<i>R&I</i>	<i>Pub + Priv</i>	<i>Medium</i>	<i>Medium</i>
Develop and standardise air transport CAT solutions which can safely and securely operate on spectrum that is not protected for aviation	<i>R&I Standards</i>	<i>Pub+Priv</i>	<i>Medium</i>	<i>Medium</i>
Environment				
Develop a regulatory framework that prioritises low-carbon routings	<i>Regulation and standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>High</i>
Study and monitor drone decarbonisation development, its impact on conventional air transport and its prospective	<i>R&I, Policy</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>High</i>
Develop procedures and a regulatory framework to minimise environmental and privacy nuisance, especially in urban areas	<i>Standards</i>	<i>Pub</i>	<i>Medium</i>	<i>High</i>
Design, develop and standardise air and ground-based CAT solutions and tools to predict and mitigate the environmental impact of air operations (from conventional air transport to fully autonomous vehicles)	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>Medium</i>
Develop and validate zero-carbon concepts, systems, interface and operations notably for taxiing	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Long</i>	<i>Medium</i>
Safety /Security and Resources				
Optimise the design of the interaction between human and automation in all operational conditions	<i>R&I, standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>Medium</i>
Plan and prepare for new skills and competences	<i>R&I, regulation standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>Medium</i>
Address the current bottlenecks in organisations acceptance of the technological and social change	<i>Regulation</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>Medium</i>
Develop and test that CAT solutions are safe and secure by design	<i>R&I, regulation standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>High</i>
Develop new manufacturing and new CAT-specific certification processes which ensure that CAT solutions are operated safely and securely	<i>R&I, regulation standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>High</i>
Develop security management systems & safe ATS performance monitoring systems and procedures	<i>R&I, regulation standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>High</i>
Develop tools, systems and procedures to ensure and monitor that CAT applications are operated safely and securely	<i>R&I, regulation standards</i>	<i>Priv+Pub</i>	<i>Short</i>	<i>High</i>
Exploit and manage safety and security intelligence	<i>R&I Standards</i>	<i>Priv+Pub</i>	<i>Medium</i>	<i>High</i>

Social and market needs in a competitive global environment

Although SESAR and Clean Sky are already addressing a significant part of the work to be covered in view of delivering competitive and low-carbon CAT solutions.

In the short term, in response to the market needs **R&I activities on autonomous vehicles and highly automated/virtualised systems** must be reinforced more precisely on:

- Air Vehicle automation and human intervention (at least some of the issues)
- Developing the system to the appropriate level of delegation of decision between the machine and the crew (on board and /or on the ground)
- Roles and responsibilities, organisational changes & associated training requirements
- Validating the contingency procedures
- Risk and opportunities of changes to single pilot /RPAS crew roles and responsibilities in the context of a flight-centric ATM approach
- Ensuring social acceptance
- Creating appropriate certification criteria
- Ensuring a safe traffic mix of 2 pilots/single pilot/fully autonomous operations
- Ensuring that the communication links are sufficient and appropriate (spectrum availability in the aeronautical band), robust to interference, latency etc.
- Coordination between telecom and aviation authorities to ensure that aviation can rely on appropriate spectrum to cope with both conventional and new entrant communication needs
- Unmanned Aircraft System regulations for freight/ passengers

In order to deliver the optimal service to the customer, CAT must develop appropriate tools to help monitor and benchmark airport/customer related processes. Finally development of European traffic management for drone sector can only be successful if it leverages appropriate expertise (i.e. those capable of delivering continuous innovation, very fast timescales, miniaturisation, short shelf-life, and new, higher levels of customer support, cybersecurity,etc.).

For urban and remote areas mobility remains more than ever the key bottleneck for their development. Air transport supported by new air vehicles, CAT services notably a smooth, low-cost, safe and secure, drone traffic management efficiently connected to the conventional traffic management, and **innovative still to be invented business models** could really improve citizen's mobility and life whilst reducing environmental footprint. Indeed, having drones deliver new services in difficult environments may significantly change the anticipated acceleration of people's migration from remote areas to urban areas. To what extent drones could change society is another unknown that needs to be addressed, as is how to deal with risky drone operations when delivering added value to the community.

These actions can only be successful in delivering the potential of CAT solutions if supported by a regulatory framework that incentivises the low-carbon solutions, addresses the liability issues and offers a framework for research and development that is adapted to the rapid-change dynamics of CAT products especially in the drone sector and their security threats. Furthermore, the air transport programmes based primarily on aviation expertise are not fully appropriate for tackling the development of CAT solutions notably the drone perspective which brings technologies and business opportunities from various sectors. There is therefore a need to develop cross-modal ventures to address these areas.

In the medium term actions should complement the SESAR and CLEAN SKY development notably hybrid vehicles and new business models but also in regards of their certifiability criteria. Rationalised highly spectrum-efficient CAT solutions are essential not to stop the development of the sector.

For the long term, R&I should be focusing on future concept of air flow management which would be required to take due account of very high number of air vehicles, their mixed levels of autonomy, the SESAR automated and virtualised concepts and changes in workforce (roles/responsibilities).

Environment

Specific actions in the environmental area are needed beyond those listed in the market needs.

In the short term it is essential to develop the regulatory framework that prioritises low-carbon routings from gate to gate and to ensure that the CAT solutions are developed as to minimise CO₂ emissions. .

In the medium term two main actions have been identified.

- Firstly, the assessment of the potential impact of drones on CO₂ reduction targets when responding to current limitations in any industrial sector and the potential for increased connectivity services needs to be further investigated so as not to negatively impact the air transport sector's commitment on climate change, safety and security. Furthermore, given the huge potential of drones for both CO₂-emission reduction and economic growth, there is a need for public monitoring of drone market development both within Europe and worldwide.
- Secondly, an appropriate regulatory framework and operational procedures are needed to minimise environmental and privacy nuisance, especially in urban areas.

Safety /Security and Resources

To maintain and further improve the current level of safety of air transport whilst introducing competitive low-carbon CAT solutions, a holistic approach is required.

In the short term priority should be given to the design/manufacturing/certification in terms not only of safety but also security insurance, together with social factors (citizen's and air transport actors).

Given the general adversity of people to change, it is essential to maximise their social acceptability. The following areas would require specific considerations: privacy and safety expectations, liability issues, risk quantification for insurance, nuisance of new vehicles/ new types of operation. This should require a better understanding of people's behaviour and culture as well as addressing the management of new types of safety and security risks.

For the air transport actors and their organisations significant resistance can be expected from change of roles and responsibility and significant potential impact on jobs, solutions to better manage this risk and to contribute to growth and employment in particular must be developed in priority. This includes new skills and competences.

In the medium term exploitation of safety and security intelligence should be optimised. Certification processes more adapted to CAT solutions should be developed. Optimisation and change in interaction between human and automation notably when considering autonomous air vehicles should be considered.

Long term actions are targeting safety and security actions in aviation as an element of the passenger-centric intermodal integrated transport system.

4.4 Waterborne Transport

The following table is a list of actions that should be undertaken to reach the technology goals and overcome barriers. Due to much higher investment levels and associated risks, it is expected that developments for deep-sea shipping will be slower than for short sea shipping, coastal shipping and inland waterways respectively. However, to simplify the table, most technical developments have been listed in one row, independent of sub-mode. This means that the time scale in some cases is too optimistic for deep sea and larger short sea ships.

<i>Description of Action</i>	<i>Type of Action</i>	<i>Sector</i>	<i>Timescale</i>	<i>Priority</i>
Open integration legislation and policy, standards	Reg,Standards	Priv+Pub	2020	High
Cyber security	Standards	Priv+Pub	2020	High
Sensor systems and situation assessment for anti-collision	R&I	Priv+Pub	2020	High
Standards for ship-shore data exchanges	Standards	Priv+Pub	2020	Medium
Acceptance criteria for autonomy	R&I,Policy	Priv+Pub	2020	High
Logistics system integration and testing	Policy,Funding	Public	2030	High
Maintenance management for zero-defects at sea	R&I	Priv+Pub	2030	High
Internet of things in remote areas	R&I,Standards	Priv+Pub	2030	Medium
New integrated VTM ⁵⁴	R&I	Priv+Pub	2030	Medium
VTM for periodically unmanned ships	Reg,Training	Public	2030	High
Port operation policy	Policy	Public	2030	High
Large-scale test facilities for autonomous vessels	Reg,Funding	Public	2030	High
EU legislation for unmanned vessels	Regulations	Public	2030	High
Pilot services for periodically unmanned ships	Policy	Public	2030	Medium
Passenger safety on unmanned ferries	Policy	Public	2030	High
Safety systems and procedures for passengers	R&I	Priv+Pub	2030	High
Last mile and modal shift policy	Policy	Public	2030	High
Voyage management for manned and unmanned navigation	R&I	Priv+Pub	2030	Medium
Shore control centre	R&I	Priv+Pub	2030	Medium
Liability for system manufacturers	Policy	Priv+Pub	2030	High
New short sea and inland UMS ⁵⁵ concepts	R&I	Priv+Pub	2030	High
Port infrastructure for automated ships	R&I	Priv+Pub	2030	High
International legislation for UMS	Regulations	Public	2050	High
International VTM legislation	Regulations	Public	2050	High
Port infrastructure for unmanned ships	R&I	Priv+Pub	2050	Medium
New deep sea UMS concepts	R&I	Priv+Pub	2050	High

⁵⁴ VTM: Vessel Traffic Management: Further developments of Vessel Traffic Systems (VTS) for sea traffic or River Information Services (RIS) for inland waterways.

⁵⁵ UMS: UnManned Ship

- **Open integration legislation, policy and integration standards:** Ship systems are characterised by relatively low integration between different manufacturers' systems and significant difficulty in adding third party functionality into each system or across systems. This is a major obstacle towards open innovation in the area of ship automation and autonomy. Existing rules work to maintain this situation and actions are required to change legislation and standards for approval of open integration systems. One should work further towards goal based standards rather than prescriptive test standards. However, this must be done in a way that permits cost effective development and testing of new functions. Standards may be developed by the industry if legal and policy actions enable new forms of open integration in ships. However, the EC should also support standards developments.
- **Cyber security:** Extensive cyber security against wilful or accidental attacks on communication or digital systems is a prerequisite for all CAT developments. The main tool to achieve this is standards, but it may require changes in policy and legislation as well as technology updates.
- **Sensor systems and situation assessment for anti-collision:** Human factors cause a large number of accidents at sea, including in particular collisions and groundings. Better sensor systems, "driver assistance" and other decision support systems on the bridge are needed to alleviate this situation. These systems are also required for fully autonomous ships.
- **Standards for ship-shore data exchanges:** More integration of ships into shore systems, including port and supply chain operations as well as operational support and third party services requires standards for data exchange between ship and shore. Interfaces to different domains such as trade and supply chains may require new approaches to inter-domain semantic interoperability. Ongoing work in the context of IMO e-navigation, ISO, IEC and UNECE needs to be supported to develop suitable standard for full integration of the digital ship into the complete logistic and transport system.
- **Acceptance criteria for autonomy:** It is necessary to develop acceptance criteria for operation of different types of autonomous vehicles. This includes technical and operational risks as well as societal acceptance. Lacking criteria, both design and approval will be difficult and costly as no common standards exists.
- **Logistics system integration and testing:** Logistics systems must be updated to provide better interaction with the different transport management systems. This should include functions to select transport mode to minimize energy use. This may require policy actions to make the different parties willing to exchange the required information. One may also have to fund initial testing of system integration, i.e. in an integrated logistics living laboratory.
- **Maintenance management for zero-defects at sea:** Current maintenance regimes on ships are dependent on human intervention and a large degree of in situ replacement and repair of defective equipment during ship operation. A large percentage of accidents in Europe is caused by defective technical systems. A new regime with higher reliability and preventive and predictive maintenance is required to enable Shipping 4.0 as well as autonomous ships.
- **Internet of things in remote areas:** Transport systems consisting of mobile units that may operate in remote areas where high capacity and highly reliable communication may not be available. This can be the Arctic regions or even sparsely populated areas on the European main land. To improve connectivity and to increase automation on waterborne vessels, it is necessary to define technical specifications that can enable Internet of Things type applications over variable quality of service data networks. Further developments on VDES⁵² should be part of this and in particular VDES⁵² (VHF Data Exchange System) via low earth orbit satellites.

- **New integrated VTM:** The technical functionality of VTM (Vessel Traffic Services – VTS at sea and River Information Services – RIS in inland waterways) must be developed to allow just in time arrival and traffic optimization to reduce congestion and fuel use. Vessel traffic management need to integrate and coordinate with commercial and logistics systems to provide just in time arrival functions.
- **VTM for periodically unmanned ships:** Regulations for VTM must be updated to allow for fully or partly unmanned operation of ships and vessels. This should also consider technical developments in the area and a training regime for VTM operators must be devised. Training may also be necessary for vessel personnel.
- **Port operation policy:** Port policies towards automated and unmanned ships and vessels need to be regulated so that ships as easily as possible can call on different ports, without having to deal with different operational and policy principles. This may include adjustments to local port byelaws.
- **Large-scale test facilities for autonomous vessels:** Large-scale test facilities (in situ through assigned sea areas as well as virtually via EMSN⁵⁶) are major gaps with regards to development of safe waterborne CAT. This can be done on regional or EU level with some public funding.
- **EU legislation for unmanned vessels:** New legislation or cooperative policies are required to enable the use of unmanned vessels within EU. Operation on inland waterways should also have EU level policies or regulations, although regional agreements may be sufficient.
- **Pilot services for periodically unmanned ships:** Pilot services also need to be changed. As an example, pilots may have to operate from land with remote control. Pilots may also get a more active role in local port operations, taking over some responsibility from shore control centres.
- **Passenger safety on unmanned ferries – policy and technology:** Unmanned short distance car or passenger ferries is a very interesting business and technical proposal. However, new safety and evacuation systems needs to be developed and corresponding legislation passed.
- **Last mile and modal shift policy:** Waterborne transport has a competitive disadvantage in being mostly dependent on fixed terminals. As size improves energy efficiency, it may also not be as flexible as other transport modes. While unmanned vessels may release some of these constraints, there may still be need for policy support to waterborne transport systems. This could be in the form of more restrictions on road transport, economic supports to ports or transport services or regulating large transport users so that they are required to maintain terminals near waterways. In particular, it is important to look at policy actions that can support integration of last mile transport services.
- **Voyage management for manned and unmanned navigation:** Anti-collision systems need to be developed to support fully unmanned navigation for the realization of fully or partially unmanned ships. This needs to be integrated with various other systems for voyage planning and execution, such as weather routing.

⁵⁶ EMSN: European Maritime Simulator Network (Ongoing development in several research project)

- **Shore control centre:** A shore control centre is useful to service manned navigation and is a prerequisite for unmanned ships.
- **Liability for system manufacturers:** An important legislative issue is the possible liability for system manufacturers in case of accidents involving automated and unmanned ships. This is currently not defined and manufactures may theoretically be made liable for any claims.
- **New short sea and inland UMS concepts:** Fully unmanned ships allows for new designs that, e.g. are much smaller and with lower speeds than existing ships. This is interesting for moving transport from road to waterborne and may allow use of alternative and low emission energy systems such as fuel cells and batteries.
- **Port infrastructure for automated ships:** Increased automation of ships will require some changes in ports, e.g. for maintenance of ships as well as increased automation also in approaches and docking.
- **International legislation for UMS:** Eventually, also international legislation (mainly from IMO) need to be updated to allow unmanned ships in international traffic.
- **International VTM legislation:** The general implementation of new VTM systems will require updates to existing international legislation.
- **Port infrastructure for unmanned ships:** Ports serving unmanned ships will require new infrastructure for mooring and fine manoeuvres. Cargo handling may or may not require new systems. Technology should probably be standardised to allow minimum investments.
- **New deep-sea UMS concepts:** As for inland shipping, unmanned operation allows new designs also for deep-sea shipping. No hotel section and superstructure, automated mooring and new cargo handling concepts can provide significant energy savings.

5. Conclusion and Recommendations

5.1 Common Themes across Modes

Based on this study several *cross-modal R&I and policy needs* can be identified:

- Cybersecurity is a key issue for all modes, with increasing automation and the underlying exchange of large amounts of data. In addition, privacy is also a worry, due to the very sensitive nature of geo-localised data, which constitutes large proportions of these data streams. Extensive cyber security against wilful or accidental attacks on communication or digital systems is a prerequisite for all CAT developments. The main tool to achieve this is standards, but it may require changes in policy and legislation as well as technology updates.
- With better integration of modes, the potential emergence of new modes and/or hybrid vehicles covering more than one mode, a move to a less rigid delineation of passenger and freight transport, and a general paradigm shift of mobility service provision, enabled by automation and connectivity, there comes a need for a new functionality of interchange locations
- Better use of big data and exchange of information among the various modes is necessary to reap the benefits big and open data has for vastly improved mobility service provision; this includes data mining, access to conventional and novel data sources, innovative uses of data sources, data analytics, innovative business models, and visualisation. This also includes connected logistics management and tracking (including last mile freight transport).
- Specific policy and regulatory frameworks on inter-modality have to be developed, in order to counteract the silo thinking of specific modes, to make movements of passengers and freight from one mode to another smoother, and to globally optimise flows over modes and loads.
- Enabled by big data, automation, and connectivity, we might soon witness the advent of new emerging vehicles, which do not fit into the rigid definition of current modes any more, both in terms of underlying infrastructure, propulsion, or loads being carried.
- The emergence of CAT technologies and enabled systems also has the potential of vastly improving the overall resilience of the transport system, enabling it to be operated in a much more interconnected and global way with widespread data sharing and robust contingency planning.
- In terms of labour market effects and requirements for a smooth transition to the implementation of CAT related technologies and services, there will be a need for developing groups of specialists in CAT applications for each transport mode and potentially for cross-modal approaches as well as the development of relevant training and education, so that future generations will be prepared for the challenges of future transport needs.
- Transition principles will have to be developed between the existing status and future solutions, for each mode of transport as well as for the overall integrated transport system as a whole. Actively managing this period is essential both for the success of these systems from a business and operator perspective, as well as in terms of guaranteeing that public sector policy objectives are adhered to, without risking potential additional negative consequences.
- Acceptance criteria for autonomy: It is necessary to develop acceptance criteria for operation of different types of autonomous vehicles. This includes technical and operational risks as well as societal acceptance. Lacking criteria, both design and approval will be difficult and costly as no common standards exist.

- Logistics system integration and testing: Logistics systems must be updated to provide better interaction with the different transport management systems. This should include functions to select transport mode to minimize energy use. This may require policy actions to make the different parties willing to exchange the required information. One may also have to fund initial testing of system integration, i.e. in an integrated logistics living laboratory.
- Internet of things in remote areas: Transport systems consist of mobile units that may operate in remote areas where high capacity and highly reliable communication may not be available. This can be the Arctic regions or even sparsely populated areas on the European main land. To realize improved connectivity and automation, it is necessary to define technical specifications that can enable Internet of Things type applications over variable quality of service data networks. This could make use of long distance, low to medium bandwidth data channels, including use over low earth orbit satellite systems.
- Last mile and modal shift policy: Waterborne and rail transport has a competitive disadvantage in being mostly dependent on fixed terminals. As size improves energy efficiency, it may also not be as flexible as other transport modes. While unmanned vehicles may release some of these constraints, there may still be need for policy support to waterborne and rail transport systems. This could be in the form of more restrictions on road transport, economic supports to ports or transport services or regulating large transport users so that they are required to maintain terminals near waterways. In particular, it is important to look at policy actions that can support integration of last mile transport services.
- Liability for system manufacturers: An important legislative issue is the possible liability for system manufacturers in case of accidents involving automated and unmanned ships. This is currently not known and manufactures may theoretically be made liable for any claims.

Recommendations coming out of this roadmap exercise relate directly to the key *barriers* that need to be overcome, which relate mainly to the following:

- Regulatory framework
- Technology development
- User acceptance and human factors
- Migration strategies and transition management
- Data management, governance, sharing, cyber-security, privacy
- Business models and business cases
- Cyber security and resilient communication networks
- Integration with transport strategies

Specific *recommendations* on how to overcome these barriers for CAT can be summarised according to the following broad categories:

Decarbonisation, Innovation, and Competitiveness

Currently partially outdated and inflexible regulatory frameworks are hindering innovation or are left behind in the increasing speed of the race to market of new IT-sector driven innovation and business models relating to CAT-based transport solutions. Furthermore, a fragmentation of regulations, standards, institutions, etc. within the EU as well as within other geographical areas can be observed. These regulatory frameworks cover both vehicles and transport services.

- ⇒ Move towards data-led and goal-based regulatory approaches for both vehicles and systems, away from the current rigid descriptive approaches hindering innovation.
- ⇒ International cooperation efforts for coordinated standards and regulation.

Overcoming Barriers and Speeding up Implementation

In terms of the R&D activities going forward there needs to be a push towards real-life system implementation with CAT as transport service carrying freight and/ or passengers, generally much more focused R&I programmes, and a paradigm shift towards data-led regulatory approaches. This assumes there is still a role here for public-sector driven development and implementation of CAT, rather than a purely industry-driven process; either will have its merits and its risks, and this questions needs to be revisited by policy makers as this space evolves.

- ⇒ Demonstrations of systems as a real-life transport system carrying passengers or freight.
- ⇒ Less broad research topics, more focused contracts, similar to US DOT system, also an EU equivalent of the US Smart City Challenge could be a good example.

Societal Needs and Behavioural Issues

There are also a number of human factors related issues to address. These include the identification of user needs a priori as opposed to waiting for market effects where business models emerge based more on a perceived demand or interest from consumers. Also, there is the important question of confidence of passengers and others involved when there is no “driver” inside the vehicle (vehicle security, personal safety, privacy, cyber security, etc.). A key recommendation here would be for the public and the private sector to embrace data as enabler for change.

- ⇒ More targeted research into user needs and requirements based on real-life applications.
- ⇒ Novel data sources, innovative use of data sources, together with analytics can be a key enabler to investigate other human factors during system trials or implementation.
- ⇒ A market based approach might naturally move towards user satisfaction based on demand.

Added Value of EU Public Support

Given the sometimes limited success of EU-funded projects on automated transport in terms of bringing products and services to the market, changes to the funding infrastructure might be necessary. This should include much more focused and results-driven R&I initiatives and a move away from demonstrations to real-life implementations, or at least demonstration very close to the market and e.g. carrying real passengers as part of daily commuting journeys.

- ⇒ Establish public-private cooperation with clear objective of establishing transport services based on vehicle automation, meeting key policy objectives.
- ⇒ For some technologies, systems, or implementation scenarios, vehicle automation is now at a level of maturity, where only limited additional R&D efforts are necessary and thus focus needs to be on active managements of the transition period which has already begun.

Interrelationship Adaptation and Mitigation

A way forward might be to focus on modes and systems requiring very minimal additional infrastructure and with more autonomy. In more extreme cases this might lead to decreased modal share of some legacy systems in the long term, as they are being replaced by more flexible, efficient, and importantly cheaper concepts. With the increasing urbanisation world-wide there could thus be an opportunity for the emergence of newly established cities, which purposely built without heavy legacy public transport infrastructure, but will be designed with CAT-enabled innovative mobility services at its heart.

- ⇒ Identification of solutions with minimal infrastructure requirements.
- ⇒ For newly established cities there might not be a need for any transport systems requiring heavy infrastructure.
- ⇒ Even in established cities more innovative systems might lead to at least temporary closure of legacy systems (including potentially completely replacing any private car usage).

5.2 *Summary of mode-specific actions*

Road transport

- Successful technological development
 - Develop resilient, affordable sensors and CAV technology operational in all weather and harsh environmental conditions
 - Define (minimum) roadworthiness requirements of higher levels of automation
 - Improve detection technology and perception intelligence
 - Identify essential changes in infrastructure, traffic rules and traffic management, define the existing gaps and technological developments
 - Develop ways to enable use of big data in (road) transport for (city) traffic management
 - Define needs, risks, solutions of ICT side of CAT, including the ICT infrastructure and cyber-security, and develop the related solutions to cover the current gaps and risks
 - Develop AI for road vehicles
- Swift adoption of CAT technology
 - Develop and incorporate mixed traffic solutions
 - Develop a European testing framework, first steps to deployment
 - Develop and agree on evaluation methodologies for systems and vehicles
 - Develop a common framework for regulation and standardisation
 - Create understanding and acceptance for the CAT technologies, including improved driver training, driver acceptance and societal acceptance
 - Demonstrate the reliability, safety and robustness of CAT
 - Enable user understanding and influence technology uptake by users, create a technology pull by cities by giving them a more central role
 - Develop strategies for transport demand management
- Ensure an attractive Europe
 - Create future workforce for EU CAT development, with all critical capabilities represented
 - Develop new business models for widespread deployment
 - Investigate potential effects of road automation on EU employment and competitiveness
 - Identify barriers for mass production of CAT, as well as recommendations to overcome the barriers. Define how to bridge the valley of death between TRL 7 and TRL 9.
 - Focus on enabling use of automation/ connected mobility for environmental friendly transport
 - Gather all stakeholders in CAT to improve the discussion, information exchange, in and beyond Europe
 - Spatial impact due to CAVs (land use, use of parking, city layout, etc.)

Rail transport

- Develop a common framework with other transport modes to share experiences and best practices of using CAT technologies within and among various transport modes
- Develop and deploy new IP based communication system for railways and a strategy for a related future technological progress
- Define optimal transition roadmap for applying CAT technologies, taking into account operational aspects of mixed traffic situations
- Develop a common framework for technical harmonisation and standardisation between (ERTMS/ CBTC), TMS and other parts of overall signalling system (e.g. interlockings)
- Develop a common framework for operational harmonisation and standardisation (ERTMS/ CBTC) for automated railways including degraded modes scenarios
- Develop a common framework for the application of higher GoA levels (3/4) in various market segments of railway domain, including related technologies, e.g. moving block
- Develop detection technology and perception intelligence for ATO operations in the ERTMS/ETCS mode (cross fertilization with the road transport)
- Develop unified testing & approval procedures for interoperable CAT applications with safety relevant functionalities
- Support the development of new COTS for a better connectivity of trains, infrastructure elements and their smart controlling, measuring and monitoring devices based on Internet of Things (IoT) with ensuring proper safety and lower life-cycle costs
- Improve rail system resilience against cyber and physical attacks
- Improve and develop the use of 'big data' in order to improve rail system maintenance and operation
- Develop a common framework for future automated maintenance techniques of rail infrastructure and rolling stock embedded in overall asset management system
- Develop the ability to manage obstacle detection in front of running trains
- Enable the fast implementation of solutions for supporting / realising energy efficient driving using information from TMS
- Develop solutions a framework for managing train integrity specifically for freight trains
- Support the development of hybridized on-board, safety relevant solutions for train positioning based on GNSS and other technologies and its reporting

Air transport

- Social and market needs in a competitive global environment
 - Develop CAT solutions in support of new operational air-transport concepts accommodating all existing and future vehicle missions
 - Develop, validate and standardise new concepts for information sharing infrastructure, fully interoperable with other transport modes.
 - Develop and validate autonomous/automated/virtualised concepts, systems, interface and operations
 - Develop certification framework including validation tools for autonomous air and hybrid vehicles which include an air component
 - Develop and test new air or hybrid-mode business model concepts with economic benefit to rural or remote areas
 - Develop a European traffic management system for the drone sector
 - Develop future concepts of air flow management (composed of mixed levels of autonomy) in a 2050 transport context
 - Set up a R&I framework adapted to the rapid-change dynamics of CAT products and their security threats
 - Develop a regulatory framework to support competitive low-carbon CAT solutions
 - Develop a regulatory framework to address changes to air transport-specific liability and insurance principles given higher levels of autonomy
 - Develop metrics and tools to quantify insurance risks of autonomous aircraft
 - Develop and validate highly rationalised-spectrum-efficient CAT solutions
 - Develop and standardise air transport CAT solutions which can safely and securely operate on spectrum that is not protected for aviation

- Environment
 - Develop a regulatory framework that prioritises low-carbon routings
 - Study and monitor drone decarbonisation development, its impact on conventional air transport and its prospective
 - Develop procedures and a regulatory framework to minimise environmental and privacy nuisance, especially in urban areas
 - Design, develop and standardise air and ground-based CAT solutions and tools to predict and mitigate the environmental impact of air operations
 - Develop and validate zero-carbon concepts, systems, interface and operations notably for taxiing

- Safety /Security and Resources
 - Optimise the design of the interaction between human and automation in all operational conditions
 - Plan and prepare for new skills and competences
 - Address the current bottlenecks in organisations acceptance of the technological and social change
 - Develop and test that CAT solutions are safe and secure by design
 - Develop new manufacturing and new CAT-specific certification processes which ensure that CAT solutions are operated safely and securely
 - Develop security management systems & safe ATS performance monitoring systems and procedures
 - Develop tools, systems and procedures to ensure and monitor that CAT applications are operated safely and securely
 - Exploit and manage safety and security intelligence

Waterborne Transport

- Open integration legislation and policy, standards
- Cyber security
- Sensor systems and situation assessment for anti-collision
- Standards for ship-shore data exchanges
- Acceptance criteria for autonomy
- Logistics system integration and testing
- Maintenance management for zero-defects at sea
- Internet of things in remote areas
- New integrated VTM
- VTM for periodically unmanned ships
- Port operation policy
- Large-scale test facilities for autonomous vessels
- EU legislation for unmanned vessels
- Pilot services for periodically unmanned ships
- Passenger safety on unmanned ferries
- Safety systems and procedures for passengers
- Last mile and modal shift policy
- Voyage management for manned and unmanned navigation
- Shore control centre
- Liability for system manufacturers
- New short sea and inland UMS concepts
- Port infrastructure for automated ships
- International legislation for UMS
- International VTM legislation
- Port infrastructure for unmanned ships
- New deep sea UMS concepts

5.3 *Mode-specific Recommendations*

Road Transport

- There is currently much going on regarding connectivity and automation of road vehicles, with R&D programmes from the public and private sector, high importance on the political agenda worldwide with both national Governments and companies racing to establish themselves as the leader in this field, and widespread reporting in the technical as well as mainstream press.
- Specific concepts exist for automation of private vehicles, trucks and buses, and also the potential emergence of more innovative shared- mobility concepts promising a paradigm shift for road-based mobility provision, particularly in built-up urban areas.
- Increased road safety, a generally better management of network and link capacities, and vastly improved convenience are the key promises of these technologies. Sufficient technology maturity levels, privacy, cyber-security, and the potential to increase rather than decrease the number of vehicles on the road are key concerns and thus areas for further work.
- Research and innovation actions proposed for road transport can be grouped into three main categories: successful technological development, swift adaptation of CAT technology, and ensuring an attractive Europe for citizens, industry and innovation.
- Missing R&D efforts relate mainly to sensor technology (particularly to deal with extreme environmental conditions) and artificial intelligence coupled with deep learning enabled by connectivity (particularly to deal with complex traffic situations, e.g. in urban areas).
- The integration with transport strategies needs to be enhanced on European, national and in particular urban level - exploiting the potential, creating synergies (e.g. with more efficient land use) and mitigating negative impacts.

Rail Transport

- The rail sector has the strategic plan to move toward a fully interoperable Single European Railway Area in which the European rail industry will play a strong and globally competitive role. The challenge is to increase the Technology Readiness Levels for traffic management and control solutions to run high capacity/speed passenger/freight trains in a sustainable and reliable infrastructure with the support of customer-oriented IT services. The R&I ambition is to offer better services to passengers and freight customers in terms of improved security, reliability, quality, competitiveness and attractiveness.
- Quantitatively, next generation rail operations and services are expected to achieve a 50% increase in the reliability and punctuality, a 100% capacity increase, and a 50% reduction of the life-cycle cost via harmonised solutions and simplified business processes. To achieve the EU policy objectives on Energy and Climate, the expected contribution is to reduce traffic congestions (especially in highly used lines/ large stations), to limit CO₂ emissions and noise pollution, and to favourite the modal shift less eco-friendly transport modes to rail.
- Research and innovation actions proposed for CAT domain in rail transport are a follow-up development of existing efforts but to the higher Technology Readiness Levels. There is also more focus on the interaction with other modes of transport (last mile) and on inclusion of rail-bounded systems (metro), not covered by ongoing Shift2Rail programme.
- A better integration of emerging national and or bilateral R&I agenda developments related to digital railway, including communication aspects, higher ETCS levels (Level 3), cyber security, big data aspects and higher grades of automation to strengthen the overall principle of European Railway Area and the global competitiveness of European railway industry in the CAT domain.

- The Clean Sky programme whose prime objectives are to reduce aviation's environmental footprint and to increase European air transport industry competitiveness, is developing new, enhanced air vehicles with less fuel consumption, emission and noise. The development of Small Air Transport (SAT) or Fast Rotorcraft also has the potential to deliver new business models which could increase connectivity beyond airports (e.g. airfields and heliports). However **there remains significant room for improvements in CO₂ reduction and competitiveness stemming from higher levels of CAT in the air vehicles (e.g. autonomous freight and passenger vehicles, new services to passengers, multimodal vehicles) .**
- In the air transport domain, CAT is already a major enabler to the SESAR programme with higher levels of automation and System Wide Information Management (SWIM) which acts as the backbone of the underlying concepts. It is ATM's ambition to meet the EU policy objectives on Energy and Climate, including the use of more fuel-efficient trajectories, seriously reduced fuel burn (at least 5-10% less fuel burn per flight), and reduced (by at least 10%) environmental impact. Beyond this programme, additional benefits from CAT could be delivered if, in particular, **SWIM were expanded to the whole transport chain and if direct routes could be the most cost-effective solution for flying from gate to gate.**
- Based on the paradigm shift towards a passenger centric travel management approach, further improvements are expected from better use of the existing infrastructure (airport nodes) in the context of an integrated transport system network which architecture in particular needs to be defined. **More work is needed to define the airport of the future notably considering new mobility services multimodal vehicles (when including a flying capability) could offer to society in particular given the potential CAT deliver in urban and remote areas.**
- Drones in the air transport sector (from RPAS to fully autonomous vehicles), highly dependent on CAT will bring a revolution to all transport modes, conventional air transport included. They have the potential to bring new technical and operational solutions which can really accelerate the decarbonisation of the whole air transport system (air vehicles, airports, ATM and interconnection to an integrated transport network) and at the same time improve European competitiveness and job creation in many economic sectors. Their development can be critical to maintaining the current very stringent **air transport safety and security levels**. Drones also bring significant challenges in terms of **social aspects** (e.g. changes in roles and responsibilities). These areas therefore **require increased attention in the near future.**
- The severity of the weather impacts is becoming one of the key barriers to the aviation network's resilience, creating severe ATM disruptions which will result in significant increase in CO₂ emissions compared with optimised 4D trajectories. By enabling better weather information, predictions, and flight-plan reconfigurations, CAT is instrumental in increasing network resilience and in reducing aviation emissions. **The research, innovation and regulatory frameworks in the context of climate change need to be reinforced.**
- Finally, to deliver their full potential, CAT solutions will rely on secure data to which access must be facilitated. Analytical tools need to be developed and recognised in the air transport certification process and appropriately managed under agreed governance. **Although significant effort has been applied in the area in the air sector, interoperability with the other transport mode requires more attention.**

Waterborne Transport

Waterborne transport plays a key role for the long-distance transportation of goods, since a very large percentage of European and global merchandise is carried by sea and handled by ports worldwide. Reducing emissions by reducing trade is not currently an option. The waterborne sector, and in particular short sea and inland waterways, also has a great potential for reducing total transport emissions by taking over some of the transport that is now being done by trucks. Thus, the R&I goals in the waterborne sector are to make it more competitive and to use CAT technology to reduce emissions from a possibly increased traffic volume. This requires R&I effort, policy support, standards and legislative developments in the following most prioritized areas:

- New waterborne transport systems based on CAT technology with reduced manning or fully unmanned operation including automation of cargo loading and discharge.
- Systems and standards for transparent, trusted and secure data transmission within and between modes, including Internet of Things in remote areas.
- An integrated logistics and supply chain system that allows improved speed optimization and shorter stays in port. This must be integrated with future vessel traffic management systems.

Glossary

<i>Term</i>	<i>Definition</i>
Transport	The movement of people and goods from one place to another.
Traffic	The flux or passage of motorised vehicles, unmotorised vehicles and pedestrians.
Traffic Management	The task to optimise the traffic flow in terms of given performance indicators under the given conditions of the existing transport infrastructure and the current traffic situation.
Network management	The task to optimise the transport infrastructure (network including ITS-infrastructure) in terms of given performance indicators to guarantee the coverage of the mobility demand of persons and goods.
Traffic Management System (TMS)	An integrated collection of subsystems for the management, the control and the guidance of traffic flows, which supports the traffic manager in his traffic management task.
Network (of transport)	Transport infrastructure (network consisting of links and nodes and ITS-infrastructure) for the movement of persons and goods.
Mode (of transport)	A term used to distinguish substantially different ways to perform transport.
Mono-modal	Involves the use of only one mode of transport for a journey.
Inter-modal (transport)	Involves the use of more than one mode of transport for a journey.
Cross-modal (traffic management)	Manages traffic across the borders of two or more modes of transport.
Multi-modal (journey)	Involves the use of multiple modes of transport for one journey.
Synchro-modal (traffic management)	Manages traffic across the borders of two or more modes of transport in a synchronised way.
Mobility (of persons and goods)	The basic need of people to be able to move themselves or their goods from A to B.
Mobility as a service	A shift away from personally owned modes of transport and towards mobility solutions that are consumed as a service.
Sectors (in transport)	Distinguish the kind of legal and economic background of actors, acting in the transport domain.
Capability	A characteristic which enables an actor to execute an activity.
Safety (to traffic)	The state of being "safe", the condition of being protected from harm or other non-desirable outcomes during a journey.
Efficiency (of transport)	An index which expresses the degree of utilisation of the capacity of the transport infrastructure.
Decarbonisation (of transport)	Transport based on low carbon power sources that have a minimal output of greenhouse gas (GHG) emissions into the environment biosphere; specifically refers to the greenhouse gas carbon dioxide (CO ₂).

List of Acronyms

<i>Term</i>	<i>Definition</i>
AIS	Automatic Identification System (for ships)
ATO	Automatic Train Operation
APM	Automated People Mover
ARTS	Automated Road Transport System
ATC	Air Traffic Control
CAT	Connected and Automated Transport
EC	European Commission
EMSA	European Maritime Safety Agency
EMSN	European Maritime Simulator Network
EU	European Union
ERTMS	European Rail Traffic Management System
FIR	Flight Information Region
GoA	Grade of Automation
IoT	Internet of Things
IP	Internet Protocol
ITS	Intelligent Transport Systems
JU	Joint Undertaking
LCC	Life Cycle Costing
MAE	Management of Aircraft Energy
MTM	Management of Aircraft Trajectory and Mission
RIS	River Information Systems
NTM	Network Traffic Management
TMA	Terminal Manoeuvring Area
UMS	UnManned Ship
VDES	VHF Data Exchange System
VHF	Very High Frequency (Radio)
VTM	Vessel Traffic Management
VTS	Vessel Traffic Services