EU EIP SA4.2

Task 3

Road map and action plan to facilitate automated driving on TEN road network – version 2020

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Document information

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Distribution

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30 June 2017	1.0	Draft road map, delivered & submitted
27 November 2019	1.1	Outline for update of road map, distributed project internally
29 January 2020	1.2	First pieces of content, discussion Haarlem meeting
26 February 2020	1.3	More content
14 April 2020	2.0	Combined inputs from writing team
22 April 2020	2.1	Version for 4.2 project management review
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22 October 2020	5.1	Version after final workshop for project internal consultation including Highways England consultation
23 October 2020	5.2	Comments from writing team
20 November 2020	6.0	Version for final approval in 4.2 team

Preface

The sub-activity 4.2 'Facilitating automated driving' of the EU ITS Platform has as a scope to prepare road authorities and operators to make decisions on facilitating automated driving and automating their own core business. This is a report of task 3 'Road map and action plan'. An initial draft road map was delivered and published in June 2017. The contents and next steps described in that document were the starting point for further work and a continued liaison process with stakeholders. This has led to this 2020 update of the Road map.

Task 3 focused on the requirements of higher levels of automated driving, and especially the requirements of automated driving towards the road authorities and operators. The scope of the task was extended to encompass requirements of automated driving to ensure the safety and the efficiency of the transportation system. This task worked in close liaison with CEDR, vehicle manufacturers, device manufacturers, digital map providers, transport operators and other fleet owners, ITS service providers and maintenance contractors as well as H2020 (2016-17 Call) and other R&D&I projects for wide commitment. The main elements of the 2020 process were national consultations in each participating member state, meetings of the CCAM platform where EU EIP participated and the final workshop in September 2020.

Task 3 was coordinated by Rijkswaterstaat (Tom Alkim, Maarten Amelink), Finland was the second lead, with participating partners Romania, Spain, Italy and UK.

Acronyms

ADS: Automated Driving System

ADAS: Advanced Driver Assistance System

AI: Artificial intelligence

AV: Automated vehicle

CCAM: Cooperative, Connected and Automated Mobility

CCTV: Closed-circuit television

CAD: Cooperative and Automated Driving

CEDR: Conference of European Directors of Roads

C-ITS: Cooperative Intelligent Transport Systems

ERTRAC: European Road Transport Research Advisory Council

EU: European Union

EU EIP: European ITS platform

FCD: Floating Car Data

FEHRL: Forum of European National Highway Research Laboratories

GiS: Geographical information System

GPS: Global Positioning System

HD: High Definition

ITS: Intelligent Transport System

L1 – L5: Level 1 - Level 5 automation

NRA: National Road Administration

ODD: Operational Design Domain

OEM: Original Equipment Manufacturer, vehicle manufacturer

PKI: Public Key Infrastructure

RTK: Real time kinetics

SAE: Society of Automotive Engineers

SMEs: Small and Medium-sized Enterprises

TMC: Traffic Management Centre

UNECE: United Nations Economic Commission for Europe

UWB: Ultra Wideband

VMS: Variable Message Sign

VRU: Vulnerable Road User

V2I: Vehicle to Infrastructure

V2V: Vehicle to Vehicle

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1. Introduction

1.1. Scope and purpose

Mobility of people and goods is a fundamental facilitating aspect for our society. Many stakeholders are working to make it as safe, efficient and clean as possible, from a business, scientific or governmental perspective. One of the most prominent developments is the automation of road transport. The introduction of automated functions in vehicles has already started. The number of equipped vehicles is expected to grow and there are promises that the functions will become more and more advanced.

Stakeholders in mobility need to consider their position on automation. What is their vision, desired direction of development? What are their interests? What options and power do they have to steer the development? What can and should they practically do to prepare?

In this document, we consider as stakeholders the road authorities and operators – since they are in the scope of the whole EU EIP project. They have a long-standing role in road infrastructure development, construction and management. Our question is: What impact does automation have for these organisations?

Stakeholders have already been considering their position on automation, on different levels, in several initiatives. This is a continuous effort since the field of automation is constantly evolving. This roadmap document is part of this continuous effort and focuses on the following topics:

- impact on and role of physical and digital infrastructure, with a specific focus on the concept of Operational Design Domain (ODD);
- cost and benefits of automation for road authorities and operators.

For both topics, the document focuses on findings and efforts so far on the one hand, and sets out a direction for future work on the other hand.

These two topics are by no means a complete coverage of the roles and responsibilities of road authorities (in which there are differences between the various EU countries anyway), but they are certainly part of their 'core business'.

The focus on the role of road authorities and operators does not mean other stakeholders are out of scope. Roles in this field cannot be considered in isolation anyway. A stakeholder consultation process was part of the preparation work for this document, so their view on future developments and roles of stakeholders are certainly part of the process.

In terms of scope of this document, for future work we look towards the year 2030 – the medium term and line with other initiatives (e.g. the ARCADE project).

1.2. Methodology and process

This roadmap document is one of the final deliverables of the sub-activity 4.2 'Facilitating automated driving' of the EU ITS Platform. It was produced under the responsibility of task 3 'Road map and action plan' of this sub-activity and was built on the results of other tasks. In addition to several internal project discussions, the timeline of the production of this roadmap was as follows:

- March 2017: Open workshop with road authorities and operators, which resulted in a draft roadmap that was published on the project website;
- October 2018: Open workshop with L3pilot project (which includes several car manufacturers as partners);
- October 2019: Open workshop with external experts within the scope of task 2 (cost and benefits) that dealt with the concept of operational design domain;
- January 2020: meeting with European Commission representatives on roadmap scope & presentation during CCAM platform meeting (working group 3);
- March 2020: presentation of project during FEHRL meeting, exchange with other projects;
- April 2020: second draft of the roadmap ready for consultation;
- May-June 2020: several consultations within partner organisations;
- June 2020: second presentation during CCAM platform meeting (working group 3);
- September 1 2020: publication of final draft roadmap document;
- September 30 2020: workshop on final draft roadmap document;
- November 2020: final version of roadmap.

1.3. Document structure

The EU EIP partners in work package 4.2 have been working on several aspects of automation which are reflected in this document. Chapters 2 and 3 focus on status, project results and way forward of the two themes mentioned above (physical and digital infrastructure, cost and benefits). Chapter 4 is about European and national policies. In chapter 5 the content is boiled down into a roadmap, while chapter 6 provides conclusions.

2. Automated driving and infrastructure

2.1. Introduction

When talking about automated driving and the role of road authorities, the first topic often is infrastructure, both the physical and the digital. Several initiatives and projects consequently have been and are still working on this subject. This chapter first describes existing material and ongoing work, then presents the EU EIP results and then looks at the way forward and next steps.

2.2. Existing material and ongoing work on requirements for infrastructure

According to SAE (SAE 2018), Operational Design Domain (ODD) is a description of the operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. An ODD can be very limited: for instance, a single fixed route on low-speed public streets or private grounds (such as business parks) in temperate weather conditions during daylight hours (Waymo 2017).

Conceptually, the role of a driving automation system in relation to a user in performance of part or all of the dynamic driving task is orthogonal to the specific conditions under which it performs that role: A specific implementation of adaptive cruise control, for example, may be intended to operate only at high speeds, only at low speeds, or at all speeds. For simplicity, however, SAE J3016's taxonomy collapses these two axes into a single set of levels of driving automation. Levels 1 through 4 expressly contemplate ODD limitations. In contrast, level 5 does not have ODD limitations. (SAE 2018)

Because of the wide range of possible ODDs, a wide range of possible features may exist in each automation level (e.g., level 4 includes parking, high-speed, low-speed, geo-fenced, etc.). Unlike a level 5 automated driving system, a level 4 system has a limited ODD. Geographic or environmental restrictions on an automated vehicle show the ODD limitations of its automated driving systems or they may reflect vehicle design limitations. (SAE 2018)

Level 1 to level 4 features are subject to limited ODDs. These limitations reflect the technological capability of the driving automation system. For example, level 4 automated vehicles that operate in enclosed courses have existed for many decades as people movers and airport shuttles. The ODD for such vehicles is very simple, well-controlled, and physically enclosed (vehicle operates on a fixed course; physical barriers prevent encroachment; protected from external events, weather, etc.). This highly-structured and simple ODD makes it technologically less challenging to achieve level 4 driving automation.

However, a level 3 or 4 automated driving system feature that operates a vehicle on open roads in mixed traffic, and does so in environments that include inclement weather, faces a significantly higher technological bar in terms of automated driving system capability by virtue of the more complex and unstructured ODD. (SAE 2018)

Note also that the ODD for a given automated driving system feature potentially encompasses a broad set of parameters that define the limits of that feature's functional capability to operate in design-specified on-road environments. It includes variables as widely ranging as specific road types, weather conditions, lighting conditions, geographical restrictions, and the presence or absence of certain road features, such as lane markings, road side traffic barriers, median strips, etc. As such, a given automated driving system feature has only one ODD, but that ODD may be quite varied and multi-faceted. Even though the ODD is composed of multiple variables, it would be incorrect to say that a driving automation feature has multiple ODDs. A feature will operate as designed only when all the ODD-defining variables satisfy design criteria. (SAE 2018)

Koopman and Fratrik (2019) point out, that the list of ODD constraints can be extensive and difficult to enumerate without significant experience. They have compiled the following list of ODD factors:

- Operational terrain, and associated location-dependent characteristics (e.g., slope, camber, curvature, banking, coefficient of friction, road roughness, air density), including immediate vehicle surroundings and projected vehicle path. It is important to note, that dramatic changes can occur in relatively short distances.
- Environmental and weather conditions such as surface temperature, air temperature, wind, visibility, precipitation, icing, lighting, glare, electromagnetic interference, clutter, vibration, and other types of sensor noise.
- Operational infrastructure, such as availability and placement of operational surfacing, navigation aids (e.g., beacons, lane markings, augmented signage), traffic management devices (e.g., traffic lights, right of way signage, vehicle running lights), keep-out zones, special road use rules (e.g., time-dependent lane direction changes) and vehicle-to-infrastructure availability.
- Rules of engagement and expectations for interaction with the environment and other aspects of the operational state space, including traffic laws, social norms, and customary signalling and negotiation procedures with other agents (both autonomous and human, including explicit as well as implicit signalling via vehicle motion control).
- Considerations for deployment to multiple regions/countries (local particularities like blue stop signs, "right turn keep moving" stop sign modifiers, horizontal vs. vertical traffic signal orientation, side-of-road changes).
- Communication modes, bandwidth, latency, stability, availability, reliability, including both machine-to-machine communications and human interaction.

- Availability, correctness and freshness of infrastructure characterization data such as level of mapping detail and identification of temporary deviations from baseline data (e.g. construction zones, traffic jams, temporary traffic rules such as for hurricane evacuation).
- Expected distributions of operational state space elements, including which elements are considered rare but in-scope (e.g. toll booths, police traffic stops), and which are considered outside the region of the state space in which the system is intended to operate.

Special attention should be paid to ODD aspects that are relevant to inherent equipment limitations, such as the minimum illumination required by cameras. (Koopman and Fratrik 2019)

The EU EIP project provided a first list of ODD attributes in 2018 (Kulmala et al. 2018a). This list was updated on the basis of e.g. the results of the EU EIP workshop in Turin 2019, and elaborated further in the MANTRA project (Ulrich et al. 2020). The resulting list of ODD attributes is shown in table X.

Table X. Attributes of Operational Design Domain ODD.(Ulrich et al. 2020)

ODD attribute	Physical / Digital infrastructure	Static / Dynamic
Road	Physical	Static
Speed range	Physical	Static
Shoulder or kerb	Physical	Static
Road markings	Physical	Static
Traffic signs	Physical	Static
Road furniture	Physical	Static
Traffic	-	Dynamic
Time	-	Dynamic
Weather conditions	-	Dynamic
HD map	Digital	Static
Satellite positioning	Digital	Static
Communication	Digital	Static
Information system	Digital	Static
Traffic management	Digital	Dynamic
Infrastructure maintenance	Physical/Digital	Dynamic
Fleet supervision	Digital	Dynamic
Digital twin of road network	Digital	Dynamic

Many attributes are related to infrastructure, both the physical and the digital infrastructure. Concerning the nature of the attributes, many of them are considered as static with regard to the availability of the service behind the attribute. In many cases, the service content itself can be quite dynamic – up-to-date information about a VMS from an information service provided in real time via the communications service to a vehicle accurately located just at the moment utilising a newly updated HD map.

The ODDs are determined by the vehicle and automated driving system (ADS) developers and manufacturers. Hence, they could be considered as being outside the scope of road authorities and operators. However, if road operators want to enable the potentially positive effects of highly automated vehicles in terms of safety, traffic flow and environment they need to be prepared to invest in order for their infrastructure to support the ODD (of different vehicles).

This information unfortunately is still limited due to market competitiveness reasons of automated vehicle and automated driving system developers. In any case, the prioritization of road operator actions and investments related to ODDs in terms of road types and relevant routes are crucial based on what national road authorities (NRAs) can afford to do. The evolution of the ODDs is driven by customer demand, and enabled by the improvement of vehicle sensors – for instance, sensors being able to deal with different kinds of weather conditions – and vehicle software – for instance, AI being able to deal with safe manoeuvring of the vehicle also in interaction with vulnerable road users in complicated urban environments. The technological development in the areas of sensors and software is currently very fast, and also hard to predict with any certainty. The overarching recommendation to road operators is however to analyse their networks and prioritize where deployment of AV use cases is most suitable and sensible. (Ulrich et al. 2020).

2.3. Existing material and ongoing work on the concept of Operational Design Domain

2.3.1. Introduction

Highly automated driving will have an infrastructure impact in two ways. First, the automated vehicles themselves may be different in their properties and behave in a different manner than human-operated vehicles leading to changes in the vehicle's impact on the infrastructure. Second, the road operators and other stakeholders may make changes to physical, digital and communication infrastructures due to the needs to provide ODD for the highly automated vehicles. According to Ulrich et al. (2020), the ODD-related impacts will be much more substantial than the impacts of the first type.

Paragraph 2.3 will describe more details, under the following subheadings:

2.3.1	Introduction
2.3.2	Physical road infrastructure
	• Road type, details and context • Special road sections • Lanes and carriageways • Shoulders and kerbs • Pavements • Road markings • Intersections and connections • Traffic signs • Road equipment or furniture • Facilities for vulnerable road users • Speed range
2.3.3	Digital road infrastructure
	• Positioning • Traffic information system • HD maps • Traffic performance status on road network
2.3.4	Communication infrastructure
2.3.5	Infrastructure operations and maintenance
	• Traffic management and control • Incidents and events • Road works • Infrastructure maintenance • Fleet supervision

Physical infrastructure solutions are defined as measures or adaptations to the static road infrastructure where, in comparison to digital infrastructure, there is no (electronic) flow of data. However, there are many hybrid elements such as VMS that require both physical (e.g. poles, mountings) and digital (e.g. display, information) elements. As consequences of CCAM and recommendations rather affecting the digital part, these hybrid forms are allocated to the digital infrastructure.

Physical infrastructure amendments should be very carefully selected. In a workshop on ODD related infrastructure requirements (Vreeswijk 2019) it was agreed that it is necessary to try to limit the dependence on physical infrastructure because of the high cost involved.

In particular, consequences to the physical infrastructure are either due to new CAD use cases having a physical impact (e.g. truck platooning) or requirements that result from CCAM use cases' ODDs. In both cases NRAs are partly able to influence whether or not such use cases are going to be allowed on their networks and which adaptions are necessary. Physical infrastructure adaptions are very costly, need to be planned far ahead and are also heavily regulated in each country with technical standards. Amendments therefore need to be well thought through. The elements most affected are either the road guidance systems (signs, markings, etc.) which are crucial for the ODD of the selected CAD use cases or the more extensive elements related to the road geometry and structural adaptations.

The following subchapters describe the additional infrastructure requirements based on the classification of infrastructure attributes by the European Commission's CCAM platform (EC 2020).

2.3.2. Physical road infrastructure

Road type, details and context

The road type often determines the ODD of the automated vehicle. Currently, most OEMs and ADS developers focus on specific road types only.

Highway autopilot and truck platooning use cases, for instance, are mainly planned for motorways. And even on motorways, those use cases are focusing on line sections and straight driving on weaving sections, and not including toll plazas, ramps or intersections.

Automated shuttles and robot taxis are mainly being developed for urban streets, and for suburban or residential areas without too complicated nor busy junctions or too many vulnerable road users.

Some automated freight vehicle use cases are being planned to operate especially in ports and other freight terminals, in addition to specific closed areas such as mines.

Valet parking is obviously focusing on parking establishments.

In addition, road design in terms of geometry and sight distances may need to be changed due to the properties of the automated vehicle. For instance, the vision system of the vehicle is totally different from that of a human driver – the sensors may cover full 360 degree view around the vehicle, and they are vertically located at a different height than the human eyes.

Special road sections

Some critical road sections may need specific attention with regard to highly automated vehicles. Tunnels may need special provisions e.g. for the accurate positioning of the vehicles and for safe operation of truck platoons in them. Traffic management/emergency systems need to be upgraded and monitoring systems, such as CCTV systems, need to be able to detect and set alarms if e.g. platoons do not dissolve. Fire protection and ventilation systems need to be checked and evaluated for suitability of platoons and driverless vehicles.

Bridges may also have specific problems. The current bridge load models and bearing capacity planning guidelines/practices have not considered the possibility of truck platoons. Bridge design standards are different in each country. On routes for truck platoons, structural recalculations of bridges need to be carried out, potentially resulting in the need of strengthening measures.

Toll plazas are quite heterogeneous in their planning and appearance making it possibly difficult for automated vehicles to navigate safely. Hence, harmonisation in the planning and management of toll plazas is likely needed. As driverless vehicles can hardly pay tolls manually at toll plazas, they require an automatic payment lane. In very many cases, such lanes exist. They may be channelized one-lane passages or often even so called “free flow multilane” solutions within the standard road cross-section.

Lanes and carriageways

Current road design standards specify the widths of carriageways and lanes based on the width and length of vehicles, while giving also a tolerance for driver behaviour. The tolerance for driver behaviour takes into account variation of the horizontal position of the vehicle in the lane as well as the space needed for making any turns on the road without venturing to the opposite lane. Typically, cars are about 2 m wide and trucks about 2.5 m while standard lane widths can very between 2.5 and 3.7 m. Automated vehicles with better lane keeping may allow for smaller tolerances for vehicle behaviour and for narrower lanes than today especially on sections without junctions or driveways. If this could result in fitting an additional lane in the carriageway, the throughput of the road would increase considerably. However, narrow lanes would likely increase rut formation as the vehicle wheel paths would necessarily be focussed in the same tracks on the lane cross-section.

One element that would have a tremendous impact on new road planning standards but also budget is the decision whether or not dedicated lanes should be provided anywhere or for any use case. For obvious reasons it will be neither feasible nor possible to provide dedicated lanes everywhere. Yet, automated shuttles or robot taxis could be granted access to existing bus lanes. Design guidelines should therefore provide indications in which areas, road types, use cases and/or traffic volumes a dedicated lane could be a recommended solution.

Shoulders and kerbs

The expected evolutions of requirements for shoulder and kerb space are quite small. This is because these are very basic requirements. Level 4 automated vehicles will need space for a safe stop in case of the termination of ODD, if stopping will be the minimum risk manoeuvre for the CCAM use case in question. Robot taxis along with e.g. automated shuttles will need a space where to pick up and drop off passengers.

On the other hand, spaces for safe stops are widely available already. Most motorways in Europe have wide enough paved shoulders for stopping a vehicle safely. However, on motorways hard shoulder running is allowed, i.e. the paved shoulders are used as a driving lane during hours of high traffic volumes. Furthermore, emergency vehicles also need the paved shoulder to reach incident sites even during traffic standing still on all lanes. It has to be noted however, that various reports and studies, like the UK report evaluating all lane running (House of Commons, Transport Committee, UK 2016), indicate that stopped vehicles on the hard shoulder provide a significant safety hazard. Therefore, the suitability of using the hard shoulder as a safe harbour needs to be carefully assessed dependent on the road situation. In the case of ODD end, the number of vehicles making a minimum risk manoeuvre can be quite large, and stopping on a high-speed road such as a motorway is not a safe manoeuvre. Thereby, slowing down and proceeding at a low speed to a large parking area beside the next exit could be a workable solution.

Most city streets have parking space along them, so that adding a sign beside the kerb and prohibiting the use of that particular space for stopping for any other purpose than picking up or dropping off passengers may suffice.

Pavements

Automated driving may lead to better lane keeping due to the use of lane centering by the ADS or due to truck platooning or highway convoy systems. Better lane keeping i.e. more exact lateral track following will possibly lead to increased pavement rutting. The potential for varying lateral offsets in platoons and convoys might be the solution to avoid pavement lifecycle cost increases due to platooning. While the potential benefits are promising, remaining challenges need to be analysed in order to take sensible measures. (Ulrich et al. 2020)

Studies are required to analyse rutting and increased road fatigue potential in case of increasing unification of wheel paths. The optimal solution could be that the ADS developers impose variation into wheel paths of automated vehicles ensuring even wear of the pavement within a lane thereby negating the possibility to reduce lane widths due to automated vehicles. Empirical data collection needs to be carried out on pilot project routes for truck platooning as a basis for pavement design and maintenance amendments. Larger effects on deterioration (rutting, skid resistance) are expected due to shorter pavement relaxation periods between axles, and in northern countries due to use of studded tyres. Lifecycle models and pavement management systems may need to be potentially adapted.

Road markings

Road markings and especially lane markings have been a basic requirement for automated vehicles due to the needs of accurate lane positioning. The case for road markings is the same for all road categories except for ports, rail yards, logistics centres, and other terminal areas, where road markings are used for various logistical purposes, indicating quite exactly where to carry out specific operations such as load or unload.

Harmonization of road marking throughout Europe would be desirable but is considered extremely difficult and unrealistic for regulatory reasons. However, technically harmonization is only really required in terms of what is machine readable and to implement this machine readability in all national road marking standards.

Today, at least some of the automated vehicle systems rely on cameras just as human drivers on their eyes for lane keeping and following the guidance painted on the road for overtaking prohibitions, channelizing traffic at junctions, etc. The robot taxis may well rely primarily on laser scanners for accurate lateral positioning and other purposes, but it is quite likely that they also utilise cameras for redundancy and other reasons.

Road markings are important also for humanly operated vehicles, but automated vehicles likely place different quality requirements for their consistency and visibility. This requires additional research.

In twenty years' time, all automated vehicles will likely have connectivity, all traffic management related information should be digitally available, including road markings, whereas accurate positioning of the automated vehicles may not require lane markings.

Intersections and connections

Ramps and junctions are considered a very difficult area for highly automated vehicles in terms of dimensions, visibility, and other issues. Today, platoons are assumed to be dissolved when entering ramps and junctions, and for instance highway autopilot may operate only on the line sections and straight driving lanes in intersection areas.

Physical road design changes are likely needed for ramps, intersections and junctions to better accommodate highly automated vehicles among human operated vehicles. There is a need to determine strategy for merging traffic for both automated vehicles and mixed traffic, for dealing with platoons on entry ramps, and for using digital ramp control or cooperative merging. Ramps may have to be lengthened and straightened due to platoons. Sufficient visibility and long enough weaving sections need to be in place for automated and conventional vehicles. Dedicated ramps and even junctions as well as buffer arrangements for ramp control may also be worthwhile to implement. (Kulmala et al. 2020)

Traffic signs

Traffic signs are similar to road markings in the ODD evolution. Camera-based sensing requires the signs and signals to be of sufficient quality and clearly visible to be machine-readable, but the information in all permanent signs at least will be available to all automated vehicles via connectivity in twenty years' time. The temporary signs and signals indicating regulations or traffic management information still need to be machine-readable, assuming that their digital coverage may not be always up to 100%. Carlson & Brown

(2019) point out, that machine-readability includes also a refresh/flicker rate of more than 200 Hz for digital sign, and that symbols are preferred against text by the vehicle industry.

Road equipment or furniture

Four kinds of road equipment needed by highly automated vehicles were identified by Ulrich et al. (2020). First, landmarks are needed to support the accurate positioning of vehicles. These landmarks need to be identified and located by the vehicle sensors, and thereby they can be equipped with radar reflectors and UWB or other radio beacons. These are only needed when the road environment itself does not offer sufficient landmarks (lamp posts, railings, buildings, etc.) already.

Second, the passenger pick-up/drop-off points are needed by some use cases. These points may be equipped with shelters and waiting areas to increase the level of service of robot taxis (and also automated shuttles likely utilising the same areas) in high passenger volume areas. These may be provided also by the transport operator.

Third, even if freight vehicles might be capable of operating on open roads, for safety reasons on some roads, road operators might wish to dedicate a specific lane or a specific time slot for them. This in turn could call for specific signing on gantries or gates providing access to the lanes or roads.

Fourth, highly automated vehicles can increase the demand for new game fences or the higher maintenance of the existing fences in order to ensure road safety on sections, where elks, deer and other large animals frequently cross the road.

Facilities for vulnerable road users

Some automated vehicle use cases likely require manoeuvring along streets and roads with only other motor vehicles alongside them, and this would require the separation of VRUs onto the footpath or specific path alongside the road as e.g. bicycle lanes would not be sufficient.

Speed range

The speed ranges are expected to evolve to reach the speed limits typically allowed for each road category as the automated vehicles are expected to comply with the speed limits. However, the sensors and software solutions of a specific vehicle and automated driving system manufacturer are likely shared with various use cases. Thereby, a robot taxi capable of driving on a motorway could drive faster than 50 km/h on a residential street, but its speed would still be restricted on such streets to 50 km/h or according to posted maximum speed limit by e.g. geofencing.

2.3.3. Digital road infrastructure

Positioning

The automated vehicle needs to be able to position itself with a few cm accuracy to ensure road safety. The vehicles utilise several independent positioning methods, such as satellite positioning and inertial positioning, mobile phone network positioning as well as car sensors and HD map positioning (Koskinen et al. 2018). The accuracy of satellite positioning has been shown to reach the 5 cm accuracy when supported by RTK (Real Time Kinetics) land stations even in the challenging northern latitudes at the Aurora test site in Finland (Koskela 2018).

As the positioning satellites such as Galileo, Glonass and GPS are already in operation, the digital infrastructure needed by the automated vehicles is thereby the network of the land stations (RTK) enhancing the accuracy of satellite positioning.

Traffic information system

There are basically two kinds of information systems required by the ODDs of highly automated vehicles. First, some systems need real-time information on incidents, roadworks, events, congestion and other disturbances on the route ahead as preview information of problems outside the range of the vehicle sensors.

Second, the automated vehicle systems usually also need information of the rules and regulations of any restrictions concerning automated driving, including real time traffic management information, and geofencing information in order to avoid routing through forbidden areas.

Distribution of digital traffic regulation becomes more and more relevant for highly automated vehicles as well as for other areas e.g. smart cities and is currently being standardized within CEN/TC 278 WG17. Current legal responsibilities and authorisation schemes vary a lot between countries, states and cities. Rules are time and place referenced similar to a digital map. This means that there will be a need to maintain and encode traffic regulations electronically to be machine readable, processed and correctly interpreted by a highly automated vehicle. (Malone et al. 2019)

The process of creating legislation at different governmental levels (national, regional and local), creating a harmonized digital equivalent for traffic regulations (e.g. normally represented thought physical signs) across Europe, and the enactment of these regulations are prerequisites but not part of the operations of distribution of digital traffic regulations. (Malone et al. 2019)

There are three options for communication of the digital traffic regulations to road users. The first two options require a secure communication and the usage of a Public Key Infrastructure (PKI). The purpose of a PKI is to facilitate the secure electronic transfer of information for a range of network activities. It is required for activities where more rigorous proof is required to confirm the identity of the parties involved in the communication and to validate the information being transferred. (Malone et al. 2019)

The options are: (Malone et al. 2019)

1. The implementing authority provides the regulations to a Trusted Digital Regulation Access Point. These regulations must be picked up by service providers, for use in their (C-)ITS services, integrating the binding information to

vehicles and (portable) electronic devices. The application of a PKI should lead the driver or automated vehicle to trust the information and observe the traffic regulation.

2. The implementing authority provides the regulations via a bidirectional communication with service providers. The further communication is similar to option 1
3. The regulations are displayed via physical infra-structure via static signs or on VMSs. This is the current practice.

Specification and standards for the different information items are useful for the provision of the real-time problems as well as regulations and traffic management information. DATEX already has standardised specifications for real-time information with usage related regulation in the delegated regulations for safety-related (EC 2013) and real-time information (EC 2015). Profiles for exchanging such information as C-ITS messages have been produced by C-Roads (2019). The SENSORIS platform is specifying the interface and data format for exchanging information between in-vehicle sensors and dedicated cloud as well as between clouds (Dreher 2019). The NordicWay project has piloted the cloud-based data exchange between vehicles and traffic management centres utilising the DATEX and AMQP standards (Scholliers et al. 2018). For traffic rules, regulations, and traffic management information, similar specifications and standards have not been produced, yet.

In the future, the national road authorities will likely introduce Trusted Digital Regulation Access Point(s) i.e. a common platform where they can share real-time traffic regulation data. Other stakeholders, e.g. digital map providers can exploit that data providing HD maps enriched with dynamic traffic regulations. (Malone et al. 2019)

Highly automated vehicles need to be aware of everything happening on the route ahead, also beyond the range of their own sensors. Here connected and automated vehicles with their sophisticated sensing systems are also part of the solution, providing high-quality information of the conditions, traffic status and incidents that they encounter while driving. The quality of traffic information needs to improve from the levels of today. The EU EIP project with its predecessors has defined the quality attributes for traffic information and four quality levels for traffic information, with the “Basic” level to be reached by all EU member states, and the second level “Enhanced” already reached by some member states. The two highest levels are expected to be reached only with high penetration of connected vehicles. (Kulmala et al. 2018b)

Due to the fact that the connected and automated vehicles will be part of the solution themselves, the quality of the traffic information will gradually improve with increased fleet penetration of connectivity and high-level automation. The prerequisite for the improvement is that the stakeholders involved – drivers and OEMs governing the data created by their vehicles, service providers and road operators governing the data from their customers and own monitoring stations – are willing to share their data. This could follow from the Data for Road Safety initiative of the European Data Task Force having a 12-month trial of the concept of sharing vehicle originated road safety related data among the stakeholders involving member states, OEMs and service providers. (DTF 2019)

To ensure the quality of traffic information, stakeholders need to use appropriate quality assurance methods and processes. While this is a standard practice for commercial stakeholders, many road authorities and operators do not have such quality assurance in place.

In the future, the road users (drivers, automated vehicles, vulnerable road users) will receive information in addition to roadside variable and dynamic message signs also via their onboard devices. The latter can be devices embedded in the vehicle by the OEMs or aftermarket or nomadic devices attached to the dashboard of the vehicle. Unfortunately, today the OEMs, service providers and app developers use a large variety of pictograms and message content in presenting the information to the user of the device. Often the contents and pictogram differ considerably from that shown by the road operator. (Haspel 2019)

For the safety of the road users, it would be good to harmonise at least the pictograms used by the different stakeholders, but preferably the whole message content (Kamalski and Rytkönen 2015). This would require some time as the road signs and vehicles have a long lifecycle, although the apps and nomadic devices have much shorter ones. On one hand, if highly automated driving will take over, the pictograms will have a decreasing significance as harmonised pictograms are more important for human drivers than for automated driving systems capable of connecting a number of pictograms to the same type of message/warning. On the other hand, the use of pictograms may be misleading. The pictogram used to indicate slippery road used by in many road operators' signs is applied in some cars as indicators of the Electronic Stability Control, while the slipperiness of the road can be indicated by a snow flake pictogram used in some road operators' signs to indicate slipperiness but also snowing. Hence, the automated driving systems would also benefit from a harmonised, consistent use of the pictograms.

Security is also important for traffic information system to avoid false alarms and otherwise to ensure road safety.

HD maps

High-Definition (HD) maps provide detailed mapping in a machine-readable format to support the ability of a connected automated vehicle to understand its precise positioning, plan beyond sensor range, possess contextual awareness of the environment and local knowledge of the road rules. Hence, HD maps can assist automated vehicles to optimize their precise positioning and control on the road surface and potentially extend their ODD. (Malone et al. 2019)

All automated vehicles make use of HD maps, which relate to the camera, radar, LIDAR and/or other sensors of the automated vehicle. Vardhan (2017) describes the four levels of the HD maps on top of the base map layer as geometric layer, semantic player, map priors layer, and real-time knowledge layer.

HD maps for automated vehicles are currently being provided by many digital map providers. Their HD maps contain different sets of data depending on the sensors used. Typically, LIDAR maps are the largest containing high definition 3D laser point clouds of the road and its surroundings.

Many road operators have built up their own GiS (Geographical information System) and digital road maps for their own asset management and other purposes. Hence, up-to-date digital maps of their road networks is a strategic asset for them, and many of them are motivated to keep this asset in their own governance. The road operators can provide their data for the HD maps either directly to the HD map providers or via a national access point. (Malone et al. 2019)

The TN-ITS platform (TN-ITS 2019) aims to ensure fresh map data and especially changes in it from the road operators to the vehicle's navigation system, for both automated and human-operated vehicles. Map makers retrieve, verify and integrate the changes in road data in their platform, and bring this to map users. TN-ITS has defined and maintained a TN-ITS specification in CEN standardisation and supported the implementation of the national digital map systems according to this specification. The current deployment covers 15 countries. (TN-ITS 2019; Dreher 2019)

According to the DIRIZON project (Malone et al. 2019), the basic process flow HD maps will be established in the short term. This means setting up the national access points or other processes for data provision, and also the specification of the profiles, formats, structures and procedures needed to handle data streams. The processes need to undergo piloting and testing. There will be agreements and digitalisation of road, lane and localization landmark data. HD maps will comprise validated data from various sources/domains that are in standardised computer-readable formats and are queried and linked via suitable web technologies, e.g. SPARQL and RDF. Data can be public and/or private data. Relevant physical infrastructure elements (e.g. road, lane and localization landmarks) have been digitised and are available to HD maps. (Malone et al. 2019)

In twenty years' time, the feedback loops for maintaining data quality have been established, the digital traffic rules are included, the HD maps localization quality has been reached, most of the physical and digital infrastructure elements have been digitised and are available to HD maps, and HD digital map achieves the data quality levels required for the decision-making process in a connected and automated vehicle. (Malone et al. 2019)

The HD maps are expected to remain an essential part of the ODD.

Traffic performance status on road network

While the information system aspects above discussed the aspects relevant to the ODD of the automated vehicles, real-time information of the traffic status on the road network is necessary for the traffic management centre(s) operating the transport network. They need to know the current and predicted status of the traffic performance on the network in order to select the appropriate traffic management actions to ensure the maximally safe and efficient performance at all times.

Here, the concept of virtual transport system or a digital twin of the transport system as an element of the digital infrastructure could be very valuable. This would allow to use the digital twin in traffic management to simulate the impacts of various traffic management measures to identify the optimal measure in real time, or in fleet management to simulate the impacts of various route alternatives to specific vehicles or transports to choose the best ones, for instance. Hence, the realisation of virtual road networks and transport systems and the development and use of real-time simulation models for them would likely benefit the road operators and traffic managers.

2.3.4. COMMUNICATION INFRASTRUCTURE

Communication is developing fast and will likely do so during the next decades as well. The basic communication types will most likely still be vehicle to vehicle short range, vehicle to infrastructure short range, and vehicle to infrastructure medium/long range. The last mentioned will likely be provided via cellular networks, but the short range V2I communications will need communication beacons beside or over the road, connected to different servers (road operators, vehicle manufacturers, service providers, fleet managers, etc.) via trunk communications such as fibre optic cabling. Road authorities and operators benefiting from the connectivity can invest in the trunk communication and roadside communication station investments in cases, where such investments are not made by other stakeholders due to their customer needs.

Radio frequencies are a limited commodity, and thereby the necessary frequency bandwidth needs to be allocated for ensuring road safety for highly automated vehicles. Key safety-relevant uses are the remote supervision of vehicles and provision of the electronic horizon to automated vehicles. It is essential to guarantee the safety prerequisite communications while keeping the lower priority demands in realistic dimensions.

A wide variety of infotainment services already exists, having sometimes high requirements for large-bandwidth low-latency communications. When automation reduces the requirements towards driver attention, the use of social media, mobile phone, in-car entertainment and mobility planning platforms will become more frequent, which can lead to safety issues.

2.3.5. INFRASTRUCTURE OPERATIONS AND MAINTENANCE

Traffic management and control

Traffic management is moving towards being an integral part of overall mobility management. In an ecosystem enhanced by significant decarbonisation and privacy priorities together with high degrees of digitalisation, traffic management is also anticipated to become closely integrated with fleet management, at least with regard to ODD management, for instance with minimum risk manoeuvres. If automated vehicles are allowed to perform a minimum risk manoeuvre which involves stopping in lane, this could pose a high safety risk for other vehicles and potentially lead to a major incident. Furthermore, as the key stakeholder in traffic management, the road authority/operator will with its traffic management and circulation plans set the scene and framework for all stakeholders involved.

One of the traffic manager's future objectives will likely be facilitating the safe operation of automated vehicles. Some road operators may decide to allocate parts of their network solely to either highly automated or human-operated vehicles. This will make ODD management as a central part of their traffic management.

The concept of cooperative traffic management needs to be fully developed and implemented building on the work carried out among other e.g. in the TM2.0 (2018), SOCRATES 2.0 (2018, 2019), and C-ITS Platform (EC 2017). The aim is to achieve optimum network performance, where all participants would behave towards reaching common optimum instead of individual optima.

In cooperative traffic management, the public authorities are recommended to act as the "orchestra conductor" and translate their mobility plans into 'standardized exchangeable data' and digital traffic management plans. The building blocks of cooperative traffic management are classification of roads based on network flow hierarchy, geo-fencing, network performance level of service targets, specific triggers for traffic management actions, and a common operation picture shared by all stakeholders. (EC 2017)

The complexity to operate and maintain ITS applications has implications on budget and resources. To ensure flexibility, the tools to develop the traffic management services for traffic including connected automated vehicles should be modular, scalable, replicable and compliant with standards.

Finally, future traffic management of automated vehicles can not overlook the ODD issue. Traffic managers need to be aware of the limitations of the highly automated vehicles operating in their networks so that they can prepare for the possible problems at road locations where the ODD of a number of highly automated vehicles will terminate due to static or dynamic conditions affecting the ODD. ODD-aware traffic managers can also provide information of likely ODD termination risks due to events, incidents, weather forecasts or other issues to the automated vehicles and their automated driving systems. There will likely be differences between vehicle ODDs but for certain situations one can assume the ODD will end for the majority of vehicles. Traffic management of the future may also contain ODD management as one functionality.

Technically, the above means establishing real-time two-way connectivity between traffic management and vehicles. The traffic management centres and roadside systems and devices need to be connected to vehicles likely via fleet managers, original equipment manufacturer (OEM) or service provider clouds. In addition, the connectivity should be used to share safety and traffic management related data. The latter will also include traffic rules and regulations as well as ODD-related data such as geofences due to or affecting

ODD, or incidents, events or conditions affecting the ODD. Specific access points to digital traffic rules and regulations (e.g. a Trusted Digital Regulations Access Point) and ODDs need likely to be set up to facilitate the cooperative traffic management in practice. High level data security is necessary for these access points. Dynamically evolving cybersecurity awareness and privacy concerns will shape this field of activity far beyond what has been standard now.

The traffic management systems have to be digitized, and the traffic circulation and traffic management plans need to be upgraded to take on board the mobility management and also ODD management aspects. Tools such as geofencing are adapted for deployment. Quite likely, the contents of these plans need to be evolving during the whole transition period from fully human-operated to a situation, where close to 100% of the vehicles are highly automated.

The digital traffic management systems will provide real-time information to HD maps and the local dynamic maps in the vehicles via the access points or also directly in specific cases such as e.g. road work zones.

Standards need to be developed for the exchange of digital traffic rules, traffic management plans, and ODD management related data as well as the related access points, including the data security solutions. Further standards or similar are needed for the harmonised traffic management and marking of road work zones and incident sites.

The role of the road authorities and operators will become more important as the “conductor” or champion in traffic management setting the framework for other stakeholders such as OEMs, fleet managers, transport operators. Thereby, the role will likely also include the supervision of other stakeholders’ traffic management related actions.

In order to reach the goals of ‘no casualties, no congestion and no emissions’ in the future, transport systems involving highly-automated vehicles with highly varying use cases, capabilities and ODDs determined by different OEMs and automated driving system providers, the status of the road authority and operator as the mobility and traffic manager of the road network needs to be ensured also legally. This means that traffic management plans and digital traffic regulations will be made legally binding to the operators of road vehicles and their automated driving systems. It also means that the vehicle manufactures, automated driving system providers, and fleet managers of highly automated vehicles are mandated to share safety, traffic management and ODD related data to the traffic managers of the networks, which they are using. At the same time, this change will increase the liabilities of the traffic managers to provide accurate and correct information to the other stakeholders. (Kulmala et al. 2020)

Incidents and events

Connected and highly automated driving will likely accelerate the automation of incident management services as quicker and more reliable incident detection improves the quality of the incident data, especially timeliness and location accuracy, to such a level that full automation of incident warnings and rerouting services is possible.

The advanced environment perception of highly automated vehicles also enables the monitoring and quality control of incident management, resulting in the improvement of the incident management services in the medium and long term. The sensors also ensure that the information of the finalisation of incident clearance will be detected and reported to road users quicker and more consistently than what is done today.

Automated safety trailers will be used to ensure the safety of incident clearance personnel at the sites. Automated maintenance vehicles may also have a role in improving the safety of incident clearance. By adopting automated safety trailers and maintenance vehicles, V2V communication can be used complementary to V2I communication, especially to warning the approaching connected vehicles for switching to another lane. Special attention must be given to the communication with non-connected vehicles. Only providing lane switching advices to connected vehicles will lead to non-connected vehicles being blocked, and an overall increase of travel time delays (van der Tuin et al. 2020).

In the management of events affecting traffic, the role of connected and automated vehicles is smaller than for incidents, but they will enhance especially the information provision processes. The role of highly automated vehicles can be important for instance in the protection of mobile events.

The environment perception systems and the related AI software in vehicles would benefit from road operators' consistent use of harmonised and standardised markings and traffic management schemes at incident sites.

Today, incident management practices tend to be based on the cooperation between three stakeholders of road authority/operator, police and rescue organisation. These are then supported by road maintenance contractors and vehicle towing and recovery service operators. In the future fleet managers will also have a role as the incidents may especially affect timetable-critical goods transport, public transport and other specific vehicle fleets.

In many countries, the police have a dominant role in incident management. The police's primary responsibility tends to be public safety and criminal investigation, while rapid clearance and the minimisation of congestion tend to be reduced priorities. (CEDR 2011)

If and when the road authorities and operators take the champion's or conductor's role in traffic management, it would be natural to maintain that role also in incident management.

The delegated regulation c) (EC 2013) already requires the stakeholders to provide access to specific types of safety-related data. Some of the data types, namely (b) animal, people, obstacles, debris on the road, (c) unprotected accident area, and (g) unmanaged blockage of a road are directly related to incidents, and cover by far most types of incidents. Thereby the legal framework exists for provision of incident related data, but it could be complemented with quality requirements and agreements for information exchange between the stakeholders.

Standardisation actions need to be pursued concerning the marking and management of incident sites taking into account the capabilities of and requirements towards highly automated vehicles. The compliance to such standards should preferably be mandated, at least on the European level. The leading or coordinating role of road authorities and operators in road incident management needs to be specifically mandated, preferably on the European level. (Kulmala et al. 2020)

Road works

The roadworks should be planned and implemented in a way that makes them easy for the vehicle drivers as well as highly automated vehicles to negotiate them in a safe manner. This calls for harmonisation on the European and global level. For connected and highly automated vehicles, harmonisation extends from the markings and road equipment (cones, barriers, and their placement, etc.) to also the presentation of the properties and traffic management of each road works site to the drivers and automated vehicles in a consistent and easily understandable manner leaving no room for misunderstandings.

Likely both stationary and mobile roadworks will quite soon mostly be equipped with hybrid C-ITS communications. Hence, the road operators need to prepare for this and provide guidelines for their deployment and use as well as to include the deployments, operation and maintenance of roadworks warning and information C-ITS service in the contracts with related contractors.

As with incident sites, there is a need to mark the roadworks in a manner easily detected and interpreted by the vehicles' sensors and software.

Automated safety trailers and road works vehicles will be used increasingly for ensuring the safety of roadworks personnel.

Road authorities and operators will likely utilise connected and highly automated vehicles in monitoring how well the automated vehicles can cope with the traffic management of road works, for instance whether their ODD can cover the roadworks site. Based on the monitoring, the roadworks management practices can be improved, and the contractors can be awarded with bonuses or penalties.

The standardized information exchange on location and layout together with defined communication protocols needs to be compulsory. Guidelines for necessary equipment in road work zones need to be developed and lane layouts, temporary marking and other guiding elements described in greater detail.

Harmonisation of roadworks management as well as related warnings and information requires standardisation activities on European level, and preferably on the global level. The compliance to the standards and related harmonisation and profiling specifications needs to be mandated on the national level, or in the European level.

Infrastructure maintenance

The mission of road infrastructure maintenance is to retain the necessary service levels of all road infrastructure assets to ensure safe road network operation. In the field of road operation and road maintenance automation can certainly contribute to increase safety of operational workers as well as road users, improve traffic flow and optimize operational cost but only in combination with connectivity. The goal should be an integrated connectivity of operational vehicles and road maintenance work-zones with a traffic management centre equipped to inform automated and conventional vehicles in real time about such works. The impact on road maintenance are therefore closely linked to the impact on traffic management.

Traditional highway operation and maintenance works (inspections, minor repairs, winter maintenance, incident management, etc.) will also be necessary in the future. Supporting the operational workers in the most critical operational tasks, like work zone protection on fast lane and winter maintenance, with automated driverless vehicles will take away main safety hazards.

Road maintenance can also benefit from new data sources on road conditions made possible through additional vehicle sensors and V2I communication. The collection of road condition data like potholes, cracks, rutting or skid resistance facilitating sensor technology of highly automated vehicles through V2I communication would greatly benefit road maintenance. Road condition data as part of safety relevant data should be made available to service and map providers to increase road safety. (Kulmala et al. 2020)

Automated winter maintenance trucks with regular operating speed would profit from smart roads, high-accuracy digital maps and commercially available powerful sensors. The technology should be first introduced in zones of minimum interaction (e.g. airports, rest areas) and depending on the experiences there, a step by step rollout in situations/areas with reduced interaction, low traffic volumes and clear road geometries would be desirable.

C-ITS solutions can make traffic around winter maintenance operation safer and smoother. In addition, it might be interesting to test the difference between a communication policy where the winter maintenance vehicle communicates its position to road users, versus a communication policy where the position is communicated in a centralised way, possibly affecting also route choice and not only lane changing behaviour.

ODD requirements could heighten the service levels and requirements for winter maintenance. Road authorities and operators will need to think about how far they are able to accommodate such increased requirements and to adapt their winter maintenance plans in terms of cycle durations, salting amounts and potentially staffing.

Overall, the digital part of an operations management centre and the traffic management centre will need to merge and have integrated communication standards.

Unmanned vehicles are legally not allowed on European roads yet except for some countries. This also includes maintenance vehicles like safety trailers or mowing robots. In winter maintenance, the solution could be convoys of winter maintenance vehicles that are at least partly driverless. Amendments to legislation are necessary to allow driverless safety trailers in particular on motorways where temporary maintenance works on the fast lane are one of the biggest safety hazard. In terms of the potential for V2I and I2V data exchange on road conditions, legal provisions have to be made in line with general data provision and data security legislation.

Road operators will need to be prepared for discussion around ODD requirements in winter conditions and the respective liability for it. If road operators decide to support ODD requirements also in winter as far as possible they will need to ensure that the service levels are met as often as possible and if not, reliable communication to highly automated vehicles is required so locations where the ODD ends are clear. Taking this further, liability will potentially provide ground for legal discussions.

Fleet supervision

Remote operation centres to monitor and supervise fleets of automated vehicles are needed by several use cases of highly automated driving, if not all of them. As the fleets will mostly belong to other stakeholders, the implementation, operation and maintenance of such centres will be the responsibility of these other stakeholders. Some national road authorities and many road operators deal with the operational maintenance and winter maintenance of their road networks. Thereby, those road authorities and operations need to set up their fleet supervision centres.

Remote supervision or even control of automated vehicles in problematic situations such as the termination of their ODD poses some legal requirements. First, the regulations must allow the remote supervision and control of the vehicle externally. Second, there has to be a legal framework for a remote driving licence for the operators at these remote fleet supervision centres. Third, there needs to be a specific secure radio frequency band allocated likely solely for the remote supervision use. Fourth, the road authorities and other road operators should be given the right to determine in which parts of their network remotely supervised or controlled vehicles can be operated, and on which terms.

2.4. Project results

2.4.1. REQUIREMENTS TOWARDS ROAD OPERATORS

As part of the EU EIP project, Courbon et al. (2019) looked specifically in the requirements that highly automated driving poses to road operators. Four main requirements were identified: 1) consistency and continuity, 2) digital infrastructure, 3) maintenance and network management processes, and 4) road classification. Specific recommendations were also made to the legal and normative framework by the project. These are elaborated in more detail below.

Consistency and continuity

Car manufacturers need consistency within network but also between networks, without too much local particularities that would require special treatment, for things like road markings, signs, road surface quality, traffic management strategies and maintenance processes.

Road operators may also have to set up some processes to ensure landmarks will be consistently visible and available for automated vehicles to position themselves on the road.

Adhering to European standards or guidelines will help to ensure cross-border interoperability and have the added benefit of avoiding the replication of work done elsewhere.

Digital infrastructure

Road operators will have to invest in the digital infrastructure, take a leading role in its development to ensure public expectations and objectives are met. They also will have to share their data (traffic, events, management strategies, circulation plans, etc.). Together with relevant service providers, they will have an instrumental part to ensure the availability of good quality real-time information on road conditions, traffic, weather, incident and event. This will have to be done through a single access point.

Sustainable service provision with long-lasting agreements and contracts with the relevant stakeholders will be necessary for the long-term viability of the digital infrastructure and the safety of all road users.

Maintenance and network management processes

It is possible that upgrading procedures and quality controls to ensure that the expected level of service is indeed consistently reached on the road network will be necessary.

Road operators will have to set up asset management and maintenance process to ensure good signs and markings visibility event in difficult weather as well as good quality of the road surface which meets the expectations. Furthermore, they will also have to ensure redundant landmarks for location, suitable communication channels hardened against adverse weather, etc.

Road classification

If the choice to open only some roads to automated driving system or to favour routing on certain roads while avoiding other, an extensive inventory and classification of the road network will have to be carried. Subsequent upgrades will have to be broadcast to autonomous driving stakeholders.

Legal and normative framework

A legal framework to proactively protect consumers and road operator rights and interest before overreaching "end user agreement" will certainly be needed, since it was needed in other similar fields (telecommunication, software, etc.).

We need a legal framework to allow independent researchers to analyse and audit automated driving systems while allowing industry stakeholders to reasonably preserve their commercial interests. This would help in strengthening the security and safety of the automated driving ecosystems.

A clarification of the roles and tasks between stakeholders will be necessary to ensure industry members have incentives to design automated driving system with road safety as a key and overruling requirement. This should be done preferably at the European level.

Since type homologation is done at European level, it should be also done so for automated vehicle type homologation. Given that procedures will probably be more complex and expensive to design, this would avoid replicating costly work both for vehicle industry and public stakeholders.

Data is one of the key enablers for connected and autonomous vehicles but data ownership, processing of private data and liability are some of the key challenges for the regulatory authorities in the EU and in the Member States. The General Data Protection Regulation (GDPR) entered into force in May 2018 and applies in particular to all transport and vehicle data that can be considered as personal data. GPDR will in principle enable the development of new services and business models but the potential threats from cyber security as well as vehicle integrity and safety need to be analysed and taken into account.

Conclusions

While the general public mostly expects improved safety, comfort and to gain back some free time it invested in its travels, road operators expect safety and efficiency improvements from the roll-out of automated vehicles on their networks. To meet these expectations, car manufacturers and service providers will need to work together with road network operators in order to define the right balance between safety, efficiency and comfort. Furthermore, road operators need to comply with strict economic constraints and also have to provide service to all road users: automated vehicles, human-operated vehicles, public transport vehicles, bikes and pedestrians alike. Hence, they will not be able to undertake comprehensive road network transformations in a short time period to accommodate highly automated vehicles.

Automated driving systems are still in heavy development and even if systems ranked up Level 4 may be available on the general market in the upcoming decade. Level 5 systems are still a long way from being ready for commercialization.

The report (Courbon et al. 2019) was based on what is currently known about advanced automated driving systems, on educated guesses by experts in the field of road transportation and not on requirements and needs expressed by car manufacturers and services providers. Those needs and requirements are just starting to emerge as progresses are made toward fully automated vehicles. It is also likely that the enhancement of sensor and software solutions due to technology development accompanied with the economics of mass production will provide extensions of the ODDs of automated vehicles in the next decades. This would result in relaxed requirements towards physical and also digital infrastructure. However, the actual developments in this respect are difficult to predict.

As automated vehicles will be introduced gradually, road operators will have to accommodate partially automated, fully automated and human drivers for a long time. It is important to find affordable solutions that accommodate also automated vehicles. Leveraging the advantages of automated driving systems should be done as soon as possible to offset the costs induced by having the different types of vehicles simultaneously on the network.

As long as there is a mix of automated and non-automated vehicles, design parameters for roads are obviously based on the manual operation of vehicles. This means that altering the roads in the sense that elements are taken away (e.g. lane markings, signs) or will have other dimensions (e.g. narrower lanes) is out of the question for time being. However, adding elements to the existing infrastructure to facilitate or enhance automated driving without negatively affecting manual driving, is a possibility (e.g. connectivity, landmarks).

2.4.2. RESULTS FROM PUBLIC EVENTS

The project organised two public events where the theme Automated driving & Infrastructure was discussed[1]:

In November 2018, a joint workshop organised by EU EIP 4.2 and an EU funded project L3Pilot took place in Athens discussing the impacts of automated driving and how to maximize the benefits. The L3pilot project unites 34 partners: OEMs, suppliers, research, SMEs, insurers, one authority and one user group. They perform large-scale piloting of automated driving with developed SAE Level 3 and Level 4 functions in passenger cars.

All relevant stakeholders from both EIP 4.2 and L3Pilot were invited to this workshop, and it attracted representatives from automotive OEMs, equipment suppliers, telecom industry, road operators, local and regional authorities, governments and research institutes, about 80 in total. The main outcomes of the presentations, discussions and polls include:

- The challenge for NRAs is how the ODD and the benefits can be optimised. Question: What should be done and who should do what?
- Safety must come first. This restricts the extension of the ODD, the circumstances must be appropriate for safely giving control to the vehicle. Another boundary is cost, we are limited by the cost of infrastructure and sensors. With unlimited

[1] A detailed report from both workshops can be found on the EU EIP website

budgets, we can work towards the ideal circumstances and/or perfect perception of the environment but of course financial resources have limits.

- How can we optimize the ODD, with communication technologies, dedicated lanes, etc? What is the role of high definition maps? How do we deal with discontinuity of the automated mode – what length should an ODD section have to be to be usable?
- The audience was asked, in a poll: can we reach high level of automation without significant investment on infrastructure? Over 80% answered No. This goes back to the issue that sensors are not enough in all current ODDs. We need cooperation between the road and the vehicle. Furthermore 90% answered that yes, we will need connectivity for automation. The question on who should decide if a road is inside the ODD, around 60% answered that road operators and OEMs should do so together, and the rest split between road operator or OEM only. The majority of people agreed that all testing stakeholders should contribute to a joint database of edge case (data around handling of rare events).
- In all these discussions, common language and terminology between stakeholders is very important, it was concluded.

In October 2019, the project organized a workshop in Torino around the theme Operational Design Domain, and aforementioned common terminology. The workshop welcomed everyone involved in shaping innovation in the automated driving. Overall, the workshop attracted in all 37 participants with 15 from industry and the private sector, 17 from public sector and road operators, and 5 representing academia and research.

The main outcomes of the presentations, discussions and work in small groups include:

- From the OEM perspective, common understanding of priorities and needs are critical to making progress together. The ODD discussion is extremely complex and depends on the use case. The main question is that who is doing what in order to have a continuous and reliable ODD. Cooperation between different stakeholders is clearly needed and hopefully EU EIP can help.
- It was explained that ODD has static, dynamic, physical and digital elements. From the road authority perspective, definition is important as it does not come free. According to the assessments already conducted there are some cost monsters like the safe harbours. Some responsibilities are clearly for road operators, some are not so obvious. ODD could also be a competitive factor from the OEM perspective, nobody wants a car which switches continuously between manual and automatic driving modes.
- From the project TransAID perspective, dealing with specific infrastructure assistance in transition areas (from automation to manual driving): what happens if the driver does not take over, what does the car do? If a vehicle stops in the

roadway in high traffic conditions for instance, this is very dangerous. Stopping in a safe space is required then.

- Several initiatives and projects are dealing with automated driving and infrastructure, and specifically ODD, we should continue this work and inform each other.
- ODD is not a static framework. Vehicle sensors will improve, and so the capabilities, so they can deal with more complicated circumstances. With regard to type approval of vehicle, some brands already work on only enabling automated functions in certain ODDs. Approval process will need to elaborated because of (wireless) updates to vehicles.
- Small group detailed discussions were held on the ODD terminology for several use cases. How should we describe the ODD, what attributes and sub-attributes are needed, building on existing work from other projects (especially the MANTRA project, see section 5.2 of this document). These discussions lead to detailed tables which are accessible on the project website.
- The ODD discussion is certainly not over yet and will need to be continued in other places. Conclusion for everyone: ask not what ODD can do for you, ask what you can do for the ODD.

The main forum where the ODD discussion was continued concerns the European Commission's CCAM platform, in which several public and private stakeholders dealing with connected, cooperative automated mobility meet. Working Group 3 (WG3) of that platform concerns Physical & Digital Infrastructure. For this group, a synthesis was made of several proposals regarding the taxonomy of physical and digital infrastructure, see the table in paragraph 2.2.

The ODD attributes identified are based on information from vehicle manufacturers' and developers' own statements and reports, data from pilots and test sites, and papers and presentations by the stakeholders involved in CCAM developments around the world. The content of the attributes has been detailed further in separate tables. The lists of physical and digital attributes do not in any way indicate the willingness nor commitment of road operators nor other stakeholders to provide these attributes to the infrastructures.

EU EIP 4.2 presented the work towards a roadmap during the January 2020 meeting of WG3 (the process). A second presentation to CCAM WG3 was done on June 29 2020, in a virtual meeting. WG3 is working towards a deliverable at the end of 2020. This will include recommendations for follow up. The EU-EIP project can provide input for this deliverable.

As agreed with the EC, this forum is used for feedback from a broad stakeholder group, while the EU EIP national workshops for the roadmap and final event focus on the road authorities and operators specifically.

2.5. Actions and recommendations

From paragraphs 2.1 to 2.4, the following actions and recommendations can be extracted:

ODD support

If road operators want to enable the potentially positive effects of highly automated vehicles in terms of safety, traffic flow and environment they need to be prepared to invest in order for their infrastructure to support the ODD (of different vehicles). However physical infrastructure amendments should be very carefully selected. It is necessary to try to limit the dependence on physical infrastructure because of the high cost involved. The technological development in the areas of sensors and software is currently very fast, and also hard to predict with any certainty. The overarching recommendation to road operators is however to analyse their networks and prioritize where deployment of AV use cases is most suitable and sensible.

There are basically two kinds of information systems required by the ODDs of highly automated vehicles. First, some systems need real-time information on incidents, roadworks, events, congestion and other disturbances. Second, the automated vehicle systems usually also need information of the rules and regulations of any restrictions concerning automated driving. In the future, the national road authorities will likely introduce Trusted Digital Regulation Access Point(s) i.e. a common platform where they can share real-time traffic regulation data.

ODD-aware traffic managers can also provide information of likely ODD termination risks due to events, incidents, weather forecasts or other issues to the automated vehicles and their automated driving systems. Traffic management of the future may also contain ODD management as one functionality. This means that traffic management plans and digital traffic regulations will be made legally binding to the operators of road vehicles and their automated driving systems. It also means that the vehicle manufactures, automated driving system providers, and fleet managers of highly automated vehicles are mandated to share safety, traffic management and ODD related data to the traffic managers of the networks, which they are using. At the same time, this change will increase the liabilities of the traffic managers to provide accurate and correct information to the other stakeholders.

Road operators will need to be prepared for discussion around ODD requirements in winter conditions and the respective liability for it. If road operators decide to support ODD requirements also in winter as far as possible they will need to ensure that the service levels are met as often as possible and if not, reliable communication to highly automated vehicles is required so locations where the ODD ends are clear. Taking this further, liability will potentially provide ground for legal discussions.

Specific physical road elements

- As long as there is a mix of automated and non-automated vehicles, design parameters for roads are obviously based on the manual operation of vehicles.

This means that altering the roads in the sense that elements are taken away (e.g. lane markings, signs) or will have other dimensions (e.g. narrower lanes) is out of the question for time being. However, adding elements to the existing infrastructure to facilitate or enhance automated driving without negatively affecting manual driving, is a possibility (e.g. connectivity, landmarks).

- Car manufacturers prefer consistency within network but also between networks, without too much local particularities that would require special treatment.
- Harmonization of road markings throughout Europe would be desirable but is considered extremely difficult and unrealistic for regulatory reasons. However, technically harmonization is only really required in terms of what is machine readable and to implement this machine readability in all national road marking standards.
- Physical road design changes are likely needed for ramps, intersections and junctions to better accommodate highly automated vehicles among human operated vehicles. Ramps may have to be lengthened and straightened due to platoons. Sufficient visibility and long enough weaving sections need to be in place for automated and conventional vehicles.
- Design guidelines should provide indications in which areas, road types, use cases and/or traffic volumes a dedicated lane for automated vehicles could be a recommended solution.
- Road authorities and operators benefiting from the connectivity can invest in roadside communication station investments in cases, where such investments are not made by other stakeholders due to their customer needs.
- Four kinds of road equipment needed by highly automated vehicles were identified: landmarks, passenger pick-up/drop-off points, a dedicated specific lane or a specific time slot for freight, and new/better game fences.
- In the case of ODD end, the number of vehicles making a minimum risk manoeuvre can be quite large, and stopping on a high-speed road such as a motorway is not a safe manoeuvre. Thereby, slowing down and proceeding at a low speed to a large parking area beside the next exit could be a workable solution.
- Toll plazas are quite heterogeneous in their planning and appearance making it possibly difficult for automated vehicles to navigate safely. Hence, harmonisation in the planning and management of toll plazas is likely needed.

Operations

- Sustainable service provision with long-lasting agreements and contracts with the relevant stakeholders will be necessary for the long-term viability of the digital infrastructure and the safety of all road users.

- Larger effects on deterioration (rutting, skid resistance) are expected. Lifecycle models and pavement management systems may need to be potentially adapted.
- Road operators may also have to set up some processes to ensure landmarks will be consistently visible and available for automated vehicles to position themselves on the road.
- To ensure the quality of traffic information, stakeholders need to use appropriate quality assurance methods and processes. While this is a standard practice for commercial stakeholders, many road authorities and operators do not yet have such quality assurance in place.
- The concept of cooperative traffic management needs to be fully developed and implemented. Public authorities are recommended to act as the "orchestra conductor" and translate their mobility plans into 'standardized exchangeable data' and digital traffic management plans, and to set the framework for other stakeholders.
- Some national road authorities and many road operators deal with the operational maintenance and winter maintenance of their road networks. Thereby, those road authorities and operations need to set up their fleet supervision centres for automated maintenance vehicles.

<u>Other digital services</u>

- The concept of a virtual transport system or a digital twin of the transport system as an element of the digital infrastructure could be very valuable. The realisation of virtual road networks and transport systems and the development and use of real-time simulation models for them would likely benefit the road operators and traffic managers.
- In twenty years' time, all automated vehicles will likely have connectivity, and all traffic management related information should be digitally available, including road markings.
- Camera-based sensing requires the signs and signals to be of sufficient quality and clearly visible to be machine-readable, but the information in all permanent signs at least will be available to all automated vehicles via connectivity in twenty years' time.
- As the positioning satellites such as Galileo, Glonass and GPS are already in operation, the needed digital infrastructure needed by the automated vehicles is thereby the network of the land stations (RTK) enhancing the accuracy of satellite positioning to the level required by highly automated vehicles.
- Many road operators have built up their own GiS (Geographical information System) and digital road maps for their own asset management and other purposes. Hence, up-to-date digital maps of their road networks is a strategic asset

for them, and many of them are motivated to keep this asset in their own governance. The road operators can provide their data for the HD maps either directly to the HD map providers or via a national access point.

- Road condition data, as part of safety relevant data, should be made available to service and map providers to increase road safety.

Legal and harmonisation framework

- In the future, the road users (drivers, automated vehicles, vulnerable road users) will receive information in addition to roadside variable and dynamic message signs also via their onboard devices. For the safety of the road users, it would be good to harmonise at least the pictograms used by the different stakeholders, but preferably the whole message content.
- The safe behaviour of highly automated vehicles at the end of their ODD needs a standardised solution for the minimum risk manoeuvre, likely specific ones for different road and traffic environments. Road operators should be a key stakeholder in such standardisation actions.
- Standardisation actions need to be pursued concerning the marking and management of incident sites taking into account the capabilities of and requirements towards highly automated vehicles. The compliance to such standards should preferably be mandated, at least on the European level. The leading or coordinating role of road authorities and operators in road incident management needs to be specifically mandated, preferably on the European level.
- Harmonisation of roadworks management as well as related warnings and information requires standardisation activities on European level, and preferably on the global level. The compliance to the standards and related harmonisation and profiling specifications needs to be mandated on the national level, or in the European level.
- A legal framework to proactively protect consumers and road operator rights and interests will certainly be needed.
- A legal framework is needed to allow independent researchers to analyse and audit automated driving systems while allowing industry stakeholders to reasonably preserve their commercial interests. This would help in strengthening the security and safety of the automated driving ecosystems.
- A clarification of the roles and tasks between stakeholders will be necessary to ensure industry members have incentives to design automated driving system with road safety as a key and overruling requirement. This should be done preferably at the European level. Since type homologation is done at European level, it should be also done so for automated vehicle type homologation.

- Road operators need to comply with strict economic constraints and also have to provide service to all road users. Hence, they will not be able to undertake comprehensive road network transformations in a short time period to accommodate highly automated vehicles. Leveraging the advantages of automated driving systems should be done as soon as possible to offset the costs induced by having the different types of vehicles simultaneously on the network.

3. Costs and benefits of automated driving

3.1. Introduction

For governments and road authorities, the benefits and costs of automated driving are an important topic in their decision-making process. With regard to benefits and impacts, they need to decide if the technology that is becoming available is safe enough for it to be permitted, and judge it on other societal criteria as well (like traffic efficiency and sustainability). Furthermore, if the government plans specific investments for the introduction, they need to consider if these investments bring sufficient returns. These kinds of calculations have a broad range of uncertainties around them. Aspects like improved traffic safety need to be monetized. And a choice needs to be made to what extent is it acceptable that the benefits that follow from government (or road authority) investment land at other stakeholders: other parts of government, commercial organisations, citizens, society as a whole etcetera?

Due to uncertainties and discussions on attribution of benefits, in the end it often involves political decisions to decide on certain investments. For 'traditional' infrastructure investments, these 'social cost-benefits analyses' are complicated as well, but at least there are standards for these calculations. In the domain of automated driving, the relations and interdependencies are quite different (more focus on the private sector) so there is certainly a challenge there.

A report was prepared and published in March 2020 within EU EIP Activity 4.2, Task 2: Impacts and economic feasibility of automated driving (Hjälmdahl et al 2020) aiming to identify and discuss the likely direct and indirect impacts of automated driving on mobility, traffic and the operations of road authorities and operators.

A comprehensive literature study was carried out and a workshop with experts from road operators and OEMs' helped to further discuss and reflect the findings from literature studies. While there are many studies made (and ongoing) about impacts and costs of automated driving, it is asked to consider the results with some caution as most of the studies rely on micro and macro simulations to derive an output and that the future reality may or may not match what the studies reflect. Also, there are many other factors such as policies, adoption of automated vehicles or technological solutions that influence if automated driving is enabled at optimal efficiency. Since the report focuses on impacts for road operators, not all direct and indirect impacts identified in referenced literature were included.

The following paragraphs summarise the main findings of the work. More details can be found in the above mentioned report.

3.2. Project results

3.2.1. IMPACTS AND BENEFITS OF AUTOMATION

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

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

At the same time, connected and automated driving will create new areas of business that will change traditional automotive business models. Manufacturers will become providers of innovative mobility solutions, rather than 'just' being producers of vehicles.

Congestion mitigation: Automated driving likely frees up spaces on the road; at an early stage of the implementation phase, automated vehicles are estimated to increase the congestion but with more and more connectivity and dedicated policies congestion could reduce.

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

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

Increased traffic safety: A significant reduction of road accident fatalities and crashes is expected as early as 2030. On the other hand, it may also happen that the road safety in a mixed traffic including both manually and automatically driven vehicles will not improve. In such a case, additional measures such as lowering of speed limits or separation of automated vehicles from human-operated ones could be taken.

Increased road capacity and reduced costs: More efficient vehicle traffic may reduce congestion and roadway costs. Reduced number of on-road vehicles via ride sharing or car sharing of automated vehicles would play a vital role in road capacity.

Savings in terms of fuel consumption can be expected, significant results are expected later, more likely from 2050.

Richer data for traffic and asset management: More effective real-time navigation, trip assignment, and dynamic routing will take place, if data from connected and automated vehicles are shared with road operators and traffic managers.

Efficient usage of infrastructure: Smarter road (intelligent freeway merging, smarter squares/roundabouts) clubbed with smart traffic and C-ITS automation in mobility would bring in more benefits in the long run. More savings of resources are needed for infrastructure, including parking and roadway constructions. It can also be pointed out that with better vehicle control and coordinated operations, the infrastructure can be made more efficient for example with automated valet parking and corresponding services.

Traffic flow smoothing: Through the shorter distances (in longitudinal and also transversal direction) between automated vehicles when driving on the road the capacity of roads could increase. Automated vehicles can even accelerate and decelerate in a coordinated way to prevent shockwaves. Mixed traffic might require dedicated lanes for optimal traffic smoothing.

Affordable and more accessible mobility: More affordable mobility services and less subsidized transit operations for public agencies may result from automated vehicles despite the higher costs to produce and maintain an automated vehicle in comparison to a human-operated one.

Mobility is also set to get more accessible and shall bring new user groups into picture. People with disabilities, handicapped, children without driving license and any other group of people who can’t drive can have access to traveling through automated vehicles.

We refer to the project report for a listing of impacts & benefits for specific types of automation use cases (Hjälmdahl et al 2020).

3.2.2. COSTS OF AUTOMATION

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

It is important to note that there is no clear indication about how these costs will be divided between road operators and other actors such as OEM’s, technology providers and users.

It is obvious that costs of vehicles and costs of advancement of automation related technology will not lie on road operators, other costs like infrastructure (digital and physical), service offering related costs (ODDs and digital maps) etc. may or may not be shared between road operators and other actors, including users in some case (through toll or paid services etc.).

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

Litman (2018) lists the societal level costs as

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

3.2.3. INTERIM-CONCLUSION

A first conclusion from the literature is that the expected effects are often more argumentative than based on empirical studies. There is also a focus on the overall effects like traffic will increase/decrease or vehicle kilometres travelled will increase/decrease rather than specifying what this implies for the road operators. This is to a large extent due to the uncertainties about what the effects really will be. The uncertainty and the wide range of potential scenarios makes it difficult to set what the costs and benefits for highly automated driving for road operators are.

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

It is still unclear what costs related to automation will be taken by road operators, what costs will be shared between road operators and other players, and what costs can be entirely skipped by road operators. The key reasons behind this being lack of knowledge from real life practices due to an early state of the technology and its adoption. The automated vehicle industry is going through what can be termed as a revolution where new business models are being introduced with an even broader array of stakeholders involved than the automobile industry has ever worked before.

All of this brings uncertainties into the picture, especially in terms of costs and responsibilities to be shared. The responsibilities of the costs are closely related to the cost-benefit relationship for each stakeholder.

3.3. Actions and recommendations

The task 2 report also presents recommendations for the automated driving ecosystem. There is a need to launch pilots; these pilots should have both a technical and a societal focus to get a better understanding of costs and benefits. These pilots would require industrial, public and academic as well as road operator cooperation. There is a growing discussion on infrastructure requirements to support automated driving. It is not clear yet who this responsibility belongs to or how these responsibilities will be shared between road operators and OEMs. It is recommended to use a common framework of definitions as facilitator for this discussion.

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

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

Data sharing is mentioned as a crucial enabler for automated systems and here more work is needed to find both safe and secure technical solutions for this as well as business models for how to share data. Several European research projects and platforms are already dealing with this and the recommendation is to continue this work on a European as well as national level. In addition, it is strongly recommended that public actors such as road operators, cities and transport organizations consider what data they have that are useful for automated vehicles and how that data can be quality assured, updated and securely communicated to the automated vehicles and shared with other stakeholders who can use the data to provide better services to road users and road operators as well.

4. European and national policies

4.1. Introduction

While preparing a roadmap for automated driving, you need to examine the starting point for the development, in this case for the road authorities and operators. This chapter describes the current situation, first for European policy and then a synthesis of national situations based on 5 countries that were involved in the road map work: Finland, Romania, United Kingdom, Spain and The Netherlands. For each, current policy and legislation, roadmap and strategy, and ongoing initiatives are described in appendix 1. It varies per country if these are specific road authority tasks, e.g. for legislation the transport ministry is often the responsible organization, but of course this is very relevant information. Of course this is just a small selection of countries, but it provides interesting background information.

4.2. European policy

About the EU and national policy frameworks

Regarding the legal frameworks and the strategies of regulatory authorities, the regulatory responsibilities are split amongst Member States and the EU. There is already a very extensive regulatory framework at the EU level for type approval of vehicles and roadworthiness (Directive 2007/46/EC, the 1968 Vienna Convention on Road Traffic and the Directive 2006/126/EC on driving license). However, at present there is no(t yet a) harmonised regulatory framework for automated driving at EU level.

The challenge facing the authorities is how to develop a coherent legal framework for some vehicles that have not yet been built. The automotive industry is moving from testing and piloting stage[1], which is based on national derogations, to type-approved commercially available automated vehicles which is needed before commercial deployment of automated vehicles.

The national regulations typically cover driver behaviour and driving licence. The automated vehicle tests are normally authorized under experimental licenses with various degrees of responsibilities. There is a lot of uncertainty, however, on up to what SAE level testing of vehicles is allowed. In more and more Member States, remote supervision (driver or supervisor not in the vehicle) is or will be allowed.

The existing EU legal and regulatory framework for road transport

The current European level regulatory framework is very extensive and covers the following main areas:

[1] See for example L3Pilot https://www.l3pilot.eu/

1. EU-wide vehicle type approval
2. Operational aspects
3. Driver behaviour and automated vehicle behaviour
4. Liability, insurance and maintenance
5. Infrastructure aspects
6. Vehicle communication and data security
7. Data ownership and privacy

All these have to be reviewed in light of increased levels of automation. Several publications call for these kind of actions (ACEA 2019; EC 2017; EC 2018; ERTRAC 2019; ETSC 2016; STRIA 2019): the EU's vehicle type approval Directive 2007/46/EC must be revised to ensure that these vehicles can respect all specific obligations for safety set out in different traffic laws across the EU. Another aspect of relevant EU legislation is the Driving Licence Directive 2006/126/EC which should be amended to include specific training and licencing on semi and full automation and how to use the technology including disengaging and re-engaging. Another is the Motor Insurance Directive 2009/103/EC which should be revised in light of the need to clarify liability for both a fully or semi-automated vehicle. The existing Directive 2008/96/EC on Infrastructure Safety Management should be revised to include requirements of automated and semi-automated vehicles such as clear road markings and adapted intersections. The EU's Roadworthiness legislation (Directive 2014/45) should also be updated. All these need cooperation of the regulatory authorities and the industry.

<u>EU actions on supporting automation and regulatory frameworks – Communication of 2018</u>

In May 2018 the European Commission adopted the communication "On the road to automated mobility (EC 2018). This communication states that connected and automated mobility is a new opportunity for Europe. Driverless vehicles will change our lives and could significantly improve road safety to bring mobility to those who cannot drive themselves (e.g. elderly or disabled people) or are under-served by public transport. They could encourage car-sharing schemes and 'mobility as a service'. They could also accelerate vehicle electrification and electro-mobility. Ultimately, driverless vehicles could free up the space wasted in parking and revolutionise urban planning.

Guaranteeing a real internal market will be key to ensure legal certainty, foster investment in the relevant technologies and protect citizens against new risks brought by driverless vehicles. A comprehensive EU strategy is needed to set the path for the EU, Member States, industry, social partners and civil society to work together and ensure that the EU seizes the opportunities offered by driverless mobility, while anticipating and mitigating new challenges for society.

4.3. Country policies

The role of national governments in supporting automation

In most EU countries, the national governments and road authorities are encouraging and supporting the trials of automated vehicles, due to the perceived benefits on road safety, environment and mobility. Automation is normally a part of a wider policy supporting smart mobility, C-ITS and the take-up of new services. In many countries support to automation is also part of industrial policy, and the support is given to the national champions and industry in order to improve their technological advantage and/or global competitiveness.

The EU and national regulatory frameworks

As explained above, there is already a very extensive regulatory framework at the EU level. The national regulatory frameworks have evolved during the time when automation was only a remote possibility. Many Member States have either started or are planning to start regulatory process which will introduce the necessary modifications to the existing regulations, or even introducing new elements.

The national regulations cover typically driver behaviour and driving licence (national traffic rules, civil and criminal law, in particular for ensuring road-safety), and the permissions for testing automated vehicles on open roads including possible derogations to the normal traffic rules. As explained above, harmonized EU rules do not exist yet and are not universally supported. Typically, the Member States are asked to report when they intend to develop national rules on automated vehicles.

The Vienna Convention and testing of automated vehicles

The Vienna Convention which is used by most Member States is already amended to allow higher level of automation. Automated driving technologies transferring driving tasks to the vehicle will be explicitly allowed in traffic, provided that these technologies are in conformity with the United Nations vehicle regulations or can be overridden or switched off by the driver.

This amendment is interpreted differently by different Member States. In most cases a trained test driver/supervisor will be required to be physically present in the vehicle to monitor the operations. Some Member States allow remote supervision. Supervision includes in all cases remote monitoring, and some mechanism for remote control (e.g. safe stopping of the vehicle). The assumption is then that when the vehicle is used on the roads there is a natural person who is the driver of that vehicle. Therefore, as long as a driver is present in the car, he will be considered responsible for the safe operation of the vehicle whilst on public roads.

Testing of automated vehicles on open roads

Most Member States either have or are working towards legislation on the granting of license for the operations and defining the responsibilities for testing of automated vehicles on open roads. The tests are authorized under experimental licenses with various degrees of responsibilities. Typically, they cover the safety of the vehicle and the trial/demonstration planning including certification, auditing and reporting.

There is, however, some uncertainty on up to what SAE level testing of vehicles is allowed, different interpretations of the SAE levels and the Vienna convention and UNECE regulations and different practises regarding the remote supervision (allowed or not). Harmonisation and standardisation of these is not, however, universally supported and is expected to take still many years.

Overview of current policies and ongoing initiatives

To collect information for this EU EIP SA 4.2 Task 3 deliverable Road map and action plan to facilitate automated driving on TEN road network – version 2020, a questionnaire was participating countries in early 2020. Project sent to members were asked to cover the following areas of ongoing activities and plans:

1. Current policy and legislation, including regulations for testing automated driving on open roads
2. Roadmaps and strategy
3. Ongoing initiatives

Most participating countries have now responded to the questionnaire, making it possible to have a very good overview of the current situation in Europe.

Current policy and legislation, including regulations for testing automated driving on open roads

All Countries have policies supporting automation, due to the perceived benefits on road safety, environment and mobility. Automation is normally a part of a wider policy supporting Smart Mobility, C-ITS, Connected Automated Driving (CAD) and the take-up of new services such as MaaS. Many countries have the ambition to be the forefront for development of automated mobility solutions in Europe.

In all countries it is possible to test and pilot automated driving on open roads, based on derogations of the existing traffic rules. In some countries Remote control (no driver/supervisor in the vehicle) is allowed.

Roadmaps and strategy

In most cases automation is seen as follow up of connected mobility, and therefore the roadmaps typically include a number of steps and actions, such as supporting ADAS, supporting the take up of C-ITS Services (including the services of the ITS Directive[1]), supporting and investments in the improvements of the infrastructure (physical and digital), and piloting and demonstration of automated vehicles or vehicle fleets including cross-border testing. The ERTRAC Roadmap of 2019 (ERTRAC 2019) is widely used as a

[1] The ITS Directive https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32010L0040

reference document and many other stakeholders, projects and collaborations work on roadmaps for automated driving (see Chapter 5.2). Also, most countries also have their own strategy and more detailed roadmaps.

Ongoing initiatives

A large number of projects are ongoing both at the EU and national level. Typical examples at the EU level are C-Roads, EU EIP, NordicWay, INFRAMIX and ARCADE. In particular, it should be noted that there are a lot of activities which support the various platforms in C-ITS and automation, such as CCAM. Cooperation with organisations like FEHRL and CEDR is supported. CEDR has projects which produce results important for road authorities such as MANTRA.

There are also many nationally funded activities. Examples are aFAS and KoHAF projects in Germany, Robusta in Finland and Drive Sweden in Sweden.

As explained above, the role of governments and road authorities is to facilitate and to encourage the trials of automated vehicles and vehicle fleets on open roads. This typically involves working together with the automotive industry on defining and implementing the required ODD for vehicles and level of infrastructure (ISAD). There are, however, uncertainties related to the costs of investment to the infrastructure, and determining who should bear the costs (industry or road authorities). In most countries, however, the tests have already been ongoing for several years and include tests of passenger cars on open roads, platooning and tests of automated buses and shuttles.

Table 1 The SAE level to which testing of vehicles is allowed, whether remote supervision (driverless vehicle) is permitted strategies and road maps.

Member State	**Testing permitted up to SAE level**	**Remote supervision permitted (Y/N)**	**Strategy and Roadmap**
Denmark	4 /5	N	An amendment of the Danish Road Traffic Act allowing testing of self-driving cars. (Ministry of Transportation 30.05.2017)
Italy	4 / 5	N	A decree authorizing the testing of AV on public roads (Ministry of Infrastructures and Transport 18.04.2018)
United Kingdom	4 / 5	N	UK Connected and Automated Mobility Roadmap to 2030 (Department for Transport 01/01/2019)
France	4	N	Development of Autonomous Vehicles Strategic Orientations for Public Action (French Ministry for the Ecological and Solidary Transition 01/01/2018)
The Netherlands	4 / 5	Y	The Pathway to Driverless Cars – a detailed review of regulations for automated vehicle technologies (Ministry of Infrastructure and the Environment 01/01/2015)
Germany	3	N	Strategy for Automated and Connected Driving (Federal Ministry of Transport and Digital Infrastructure 01/01/2015)
Finland	5	Y	Road Transport Automation Road Map and Action Plan 2016–2020 (Finnish Transport Agency 01/01/2016)
Sweden	4 / 5	Y	OmAD Environmental analysis Automated driving (The Swedish Transport Agency 21.08.2020)
Romania	3	N	National Strategy for Multimodal Transport (National Motorway Company)
Spain	4 / 5	N	Spanish approach on Autonomous driving (Dirección General de Trafico 01/01/2016)

5. Roadmap from the perspective of road operators

5.1. Introduction

Connected and automated driving is a development on both the short term and the long term. First deployments are already visible on our streets, but there are many uncertainties in the years ahead. That is why many stakeholders, projects and collaborations work on roadmaps for automated driving. These documents can be categorized into one or more of the following types:

- describe a desired situation in a certain year in the future as an inspirational vision
- describe the actions that are advisable or necessary from stakeholders on several moments in time
- describe several different future situations in scenarios
- promote a certain viewpoint or position or sell a product by providing argumentation and a 'story-line'
- describe the outcome of a joined stakeholder effort to set up the roadmap, with that process of understanding and discussing each other's positions being a goal in itself.

In this roadmap, the focus is on the second goal – what are the advisable or necessary actions? This is in line with the focus of the EU EIP project as a whole, to work on the tactical and operational side of ITS. Scenarios and desired future situations are on the strategic side of connected & automated driving, so for that element we draw on work done in CEDR, ERTRAC and ARCADE.

5.2. Other roadmaps

Many stakeholders, projects and collaborations work on roadmaps for automated driving. Without trying to be complete, this chapter presents an overview of other roadmap work. The focus is on the ones that have a link with the EU EIP scope. For each, the following subjects are described:

- Type – see types as explained in chapter 5.1
- Scope – description of background & organisations behind
- Short summary of contents of document
- Relevance for road authorities/EU EIP – interpretation of importance

(texts in italics are quotes from the documents)

5.2.1. OVERVIEW

Strategic Research and Innovation Agenda for CCAM (to be published in 2020)
Authors: CCAM platform members and European Commission
Type: Describe a desired situation in a certain year in the future as an inspirational vision & Describe the outcome of a joined stakeholder effort to set up the roadmap
Scope: The platform is a group of both private and public stakeholders to advise and support the EC in the area of open road testing and making the link to pre-deployment activities. They propose to form a partnership that aims to harmonise European R&I efforts to accelerate the implementation of innovative CCAM technologies and services.
Short summary: The vision of the Partnership is: "European leadership in safe and sustainable road transport through automation". The aims will be elaborated in the SRIA document (to be published in 2020) that describes the envisaged portfolio of activities to support the full and effective achievement of the objectives and expected impacts of the proposed Partnership. It builds on previous strategic R&I recommendations on CCAM.
Relevance for road authorities/EU EIP: The road authorities are giving input to the platform work through their member state representation and CEDR. The research agenda describes the focus of future work on CCAM.

ARCADE CAD consolidated roadmap Year 1 (November 2019)
Authors: ARCADE project consortium (public, industry and research sectors, stakeholder associations)
Type: Describe several different future situations in scenarios & Describe the outcome of a joined stakeholder effort
Scope: Bring together a consolidated multi-stakeholder view on the development of CAD in Europe into three development paths, highlight ongoing activities and identifying challenges and key priorities. This is the first-year version of the roadmap document. It will be updated annually.
Short summary: Document describes indicative development paths for high automation of different vehicle types, and key priorities and challenges on 12 thematic areas.
Relevance for road authorities/EU EIP: The notions on the themes, 'physical & digital infrastructure' and 'deployment' are the most relevant. Includes: *Define the involvement of public authorities in the early stage of deployment to create trust among stakeholders, Investigate the use of common definitions, create living labs, cross-border enabling.*

ERTRAC Connected Automated Driving Roadmap (March 2019)
Authors: members European Technology Platform ERTRAC - experts from the industry, research providers and public authorities.
Type: Describe the outcome of a joined stakeholder effort
Scope: Document contains development paths and timeline for automation in three different categories of vehicles, these are used by several other initiatives as starting point.
Short summary: Common definitions of automation levels and systems, challenges for the implementation of higher levels of automated driving functions, development paths are provided for three different categories of vehicles. In 2030, the timeframe for this EU EIP roadmap, ERTRAC envisages that the following level 3 and level 4 use cases are implemented on highways: • Traffic Jam Chauffeur (cars & trucks) • Highway Chauffeur (cars & trucks) • Highway Autopilot including Highway Convoy • Highway Pilot Platooning (trucks) • Highly Automated Vehicles in Confined Areas (trucks) • Highly Automated Vehicles Hub-to-hub operations (trucks) • Highly Automated Vehicles on Open Roads (trucks)
Relevance for road authorities/EU EIP: The notions on the themes, 'physical & digital infrastructure' and 'deployment' are the most relevant. Includes: *What are the roles and responsibilities of the different stakeholders of PDI for CAD? Should the vehicle cope with any road infrastructure, and if not, what demands can be set to adapt the existing PDI? How and to what degree will joint concepts by automotive sector, fleet and road operators improve traffic management? Large scale tests, alignment with deployment of cooperative and connected ITS*

STRIA Roadmap on Connected and Automated Transport (CAT) (April 2019)
Authors: EC DG RTD with contribution of experts of different stakeholder groups from industry, academia and national authorities
Type: Describe the actions that are advisable or necessary from stakeholders on several moments in time;

Scope: Roadmaps for the road, rail and waterborne transport modes explaining what has to be done to overcome the hurdles and gaps between the state of the art in CAT in Europe and the European Union's objectives.
Short summary: action plan & recommendations for each mode plus an overarching conclusion for cross modal interactions
Relevance for road authorities/EU EIP: baseline for many follow up work including CCAM platform, in terms of themes and actions defined.

EU EIP 4.3 roadmap - actions for CNC digitalization (to be published in 2020)
Authors: EU EIP project work package 4.3 members
Type: Describe the actions that are advisable or necessary from stakeholders on several moments in time
Scope: looking at measures that deal with the corridor level; how can we support the corridor approach with ITS? What needs to be done on the corridor level? They are basically designed for and aimed at facilitating goods transport. "Corridors are for transport; traffic takes place in networks". Looking at development needs in the shorter time perspective, up to 5 years.
Short summary: Concrete proposals for actions to be picked up by the CNC coordinators and future European platforms.
Relevance for road authorities/EU EIP: projects is specifically aimed at road authorities

The Future of Road Transport - Implications of automated, connected, low-carbon and shared mobility (2019)
Authors: JRC, European Commission's science and knowledge service
Type: Describe the actions that are advisable or necessary from stakeholders on several moments in time & Promote a certain viewpoint or position or sell a product by providing argumentation and a 'story-line'
Scope: Assesses the whole road mobility system, not just cars.
Short summary: The massive changes on the horizon represent an opportunity to move towards a transport system that is more efficient, safer, less polluting and more accessible to larger parts of society than the current one centred on car ownership. New transport technologies will not spontaneously make our lives better without upgrading our transport systems and policies to the 21st century. The improvement of governance and the development of innovative mobility solutions will be crucial to ensure that the future of transport is cleaner and more equitable.

Relevance for road authorities/EU EIP: recommendations towards (road) authorities include that uncoordinated competition among service providers and a lack of leadership by transport authorities could lead to more traffic problems and an unbalanced provision of capacity. Policymakers must improve governance systems and involve citizens in the roll-out of innovative mobility solutions.

Manifesto European Automotive and Telecoms Alliance EATA (2019)
Authors: EATA, which has member companies from across the automotive and telecom sectors in Europe.
Type: Promote a certain viewpoint or position or sell a product by providing argumentation and a ‘story-line’
Scope: message from industry towards new European Commission and European Parliament
Short summary: Four focus areas are presented: Enabling a clear framework to foster investment and innovation, avoiding fragmentation by ensuring coordination of policy initiatives, Technology neutrality is critical for the development of CAM, accelerating cooperation and leverage on the international stage.
Relevance for road authorities/EU EIP: call on governments including road authorities to align policy and regulation frameworks, be technology neutral and also cooperate worldwide.

ACEA - Automated driving, Roadmap for the deployment of automated driving in the European Union
Authors: European Automobile Manufacturers’ Association (ACEA)
Type: Promote a certain viewpoint or position or sell a product by providing argumentation and a ‘story-line’
Scope: It provides a check-list for policy makers which details the legislative framework that must be put in place at the international, EU and national level. Moreover, it contains a timeline setting out the next steps that must be undertaken over the coming years
Short summary: the checklist for instance has the following elements: technical regulations/functionalities, Cybersecurity, Traffic rules, Road infrastructure
Relevance for road authorities/EU EIP: specifically, the documents asks for: Harmonisation of national road traffic laws and road signs, regulation or standard on interface vehicle and traffic management, and for Road Infrastructure Safety Management (RISM) Directive.

CEDR CAD & MANTRA (to be published in 2020)

Authors: MANTRA project consortium (of the CEDR research programme's Automation Call 2017) in liaison with CEDR CAD Working Group
Type: Describe the actions that are advisable or necessary from stakeholders on several moments in time
Scope: Responds to questions of a) what are the influences of automation on the core business on national road authorities in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes, and b) how will the current core business change? A road authority and operator oriented action especially targeting the impacts of highly automated driving (specific five use cases) on mobility, safety and efficiency as well as physical and digital road infrastructures by 2040, and the ODD-related requirements towards road operators.
Short summary: The project has provided forecasts of highly automated driving use cases in vehicle fleets, assessed the impacts of automated driving on especially traffic flow, infrastructures, and road authority core business. The project concludes its findings in a roadmap for adaptation of road authority core business. The contains a list of more than 90 actions in the domains of physical infrastructure, digital infrastructure, operations and services, and road planning and maintenance.
Relevance for road authorities/EU EIP: The results are directly applicable to road authorities as they were the target group in the first place. The road map provides an immediate starting point for the EU EIP roadmap by providing a long list of actions to be considered also in the EU EIP roadmap.

There are several more relevant initiatives and documents to be shortly mentioned here:

- Projects dealing with automation and infrastructure that are also producing roadmaps like Inframix, TransAID.
- Deployment projects of C-ITS or innovative traffic management that describe next steps following completion of their work;
- Conclusions from high level meetings, following up on the Declaration of Amsterdam from 2016;
- National roadmaps, mostly focussing on contribution of CAD to policy goals and role of national public and private stakeholders. For instance, the UK roadmap coordinated by dedicated organisation Zenzic with specific goals an steps towards them;

There are many more influential roadmap documents that are of somewhat older date (e.g. GEAR 2030, from 2017) that are not listed here to avoid an overload of information. Most of the more recent documents are in fact building on those documents, so many notions are taken over and updated over time.

5.2.2. Reflection

There are obviously many stakeholders working on roadmaps, individually and in collaboration. They have different goals and scopes, but the results also have a lot of commonalities. It is clear that no one knows what the future will look like, and that the future of automation is a bit further away than many expected a couple of years ago. In the meantime, everyone tries to anticipate and call for or take the actions to optimise and/or protect their own core business while trying to avoid investments that turn out to be unnecessary later. But the future development is not an isolated process – the stakeholders' strategies and actions shape that future themselves, while still being largely dependent on technological progress and societal acceptance from others.

The various roadmaps call for actions; many are on policy and regulation which would be more on the plate of the ministries, but they could imply big changes for the work of road authorities. Actions on traffic management and joint development of the vehicle-infrastructure ecosystem are aimed at road authorities directly.

With regard to the relevance for road authorities and EU EIP, we can say that there is a gradual shift from: automated vehicles are coming soon, we need to do something quick to facilitate them, to: we see potential benefits from automated vehicles but also many hurdles, what could we do at what cost and is that in balance with the benefits for our organisation and society? How can we facilitate that the benefits arrive quicker than they would without any action for our side?

When thinking about actions to be taken by stakeholders in general and road authorities and operators specifically, the following principles should be considered:

- Acting with a view on the future always involves a certain risk; each stakeholder should decide for itself what risks it is prepared to take. Taking no action or keeping all options open is also a choice, with its own risks;
- Making a certain choice could increase the chance of a desired future becoming reality;
- Defining actions does not mean that a final decision is already taken, they can act as framework for further discussions with others; on the other hand, too many or radical changes in strategy may not help in creating trust and may even cause choices of others becoming disinvestments;
- Compare yourself with stakeholders in a similar position, learn from them or make joined strategies; commercial stakeholders may not to be keen to give these kinds of insights however;
- Be aware of 'blind spots' in your decision making process; e.g. unexpected technical developments in other sectors or lack of focus on public perception (too much thinking from a technology perspective) may lead to quite a different picture;

Furthermore, you need to try including flexibility in the process. Remaining flexible is difficult, since others will keep on pushing for a firm position. And to be able to secure funds for investments, you need to take a position in time.

5.3. Actions and recommendations

5.3.1. INTRODUCTION

In this document, we considered the stakeholder group of road authorities and operators What impact does automation have for these organisations? We focused on a couple of topics:

- impact on and role of physical and digital infrastructure, with a specific focus on the concept of Operational Design Domain (chapter 2);
- cost and benefits of automation for road authorities and operators (chapter 3).

The actions and recommendations from those topics are summarised here in a structured way and we add the following information:

- Out of the 45 actions, 14 got the most priority votes overall in the national consultations. They are marked with an asteriks* in the table.
- the (other) stakeholders involved (other than road authorities and operators). Road authorities and operators would be the so-called champion for each action (they will take the lead) unless stated otherwise.
- the resources needed (money, time, power, cooperation, …)
- the timing (short term: next 3 years, medium term: next 10 years, long term: > 10 years).
- Some actions were imported from other sources, if this is the case the source is mentioned:
  - MANTRA project (Kulmala et al. 2020)
  - Roadmap smart mobility in the Netherlands (Rijkswaterstaat 2020)

5.3.2. IMPACT ON AND ROLE OF PHYSICAL AND DIGITAL INFRASTRUCTURE

Data & information provision

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
1*	Sustainable, long term digital service provision	OEMs, service providers, mobile network operators and	Money, clarification of legal and	Short term

		providers, HD map providers	organisational consequences	
2*	Appropriate quality assurance methods and processes for data provision	OEMs, service providers, HD map providers	Money, clarification of legal consequences	Short term
3*	Supply real-time information on road status and regulations	OEMs, service providers, HD map providers	Cooperation, clarification of legal consequences	Short term
4	Make information of traffic signs available via connectivity	Service providers, HD map providers	Money, clarification of legal consequences	Short term
5	Discuss and prepare mandate for fleet managers and OEMs to provide feedback on HD maps	OEMs, fleet operators, HD map providers, service providers	Cooperation	Short term **Action Source: MANTRA**
6	New approaches to road condition data collection for deterioration monitoring	OEMs, fleet operators, HD map providers, contractors	Cooperation	Short term **Action Source: MANTRA**
7*	Set up digital twin of transport system	Service providers, HD map providers, other experts	Money, development capacity	Medium term
8*	Use of automated vehicles to monitor the performance of road works management	OEMs, fleet operators, HD map providers, contractors	Cooperation	Medium term **Action Source: MANTRA**
9	Supply information on ODD termination risks	OEMs, fleet operators, HD map providers	Cooperation, clarification of legal consequences	Medium term

Harmonisation & Standardisation

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
10*	Common framework of definitions for infrastructure requirements discussion	OEMs (champion together with authorities), ADS providers, HD map providers, other experts	Time and commitment	Short term

11*	Implement machine readability in road marking standards	OEMs, ADS providers	Time, clarification of legal consequences	Short term
12*	Consider more consistency in road network and less particularities	OEMs	Time, money	Medium term
13	Harmonisation of toll plazas	OEMs, ADS providers, toll operators	Money, time	Medium term
14	Consider harmonising the pictograms and message content used by road operators and OEMs	OEMs, service providers, HD map providers	clarification of legal consequences	Medium term
15	Standardisation of minimum risk manoeuvres	OEMs, ADS providers	Time, money, clarification of legal consequences	Medium term
16	Standardisation concerning the marking and management of incident sites	OEMs, ADS providers, HD map providers, incident managers	clarification of legal consequences	Medium term
17	Harmonisation of roadworks management	OEMs, ADS providers, contractors	clarification of legal consequences	Medium term

<u>Possible Investments</u>

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
18*	Develop investment scenarios for road side systems vs smart vehicles. What is needed in light of evolution of automated vehicles?	OEMs, ADS providers, HD map providers, other experts	Money, stakeholder cooperation	Short term **Action source: RWS roadmap**
19	Consider investing in roadside equipment where needed for road authority purposes and others do not	Telecom industry, mobile network operators	Money	Short term
20	Prepare to invest to support the ODD but be very selective	OEMs	Money, cooperation	Medium term
21	Additional emergency bays, wide shoulders and safe	OEMs, ADS providers other experts	Money	Medium term

	harbours where needed, to accommodate minimal risk manoeuvers			**Action Source: MANTRA**
22	Network of land stations for satellite positioning	*not the task of the road operators in many countries so likely not the champion* Land survey agencies, service providers, OEMs	Money, stakeholder cooperation	Medium term
23	Fleet supervision centres for own automated winter maintenance vehicles	OEMs, fleet operators, contractors, other experts	Money	Long term

Research, development, stakeholder cooperation

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
24	Monitor developments in smart mobility as baseline for decision-making. Includes fleet composition and user acceptance.	Other experts, research and academia	Cooperation	Short term **Action source: RWS roadmap**
25*	Assess best solution for ODD end (many minimal risk manoeuvres)	OEMs, ADS providers, AV experts	Time, Money (piloting)	Short term
26*	Develop concept of cooperative traffic management	OEMs, fleet operators, service providers	Money, clarification of legal consequences	Short-medium term
27	Further specification and official introduction of Road categorization (ISAD levels) for digital and physical infrastructure	OEMs, ADS providers, HD map providers	Cooperation	Medium term **Action Source: MANTRA**
28	Assess need for adaptations in ramps, intersections and junctions	OEMs, ADS providers, AV experts	Money, time	Medium term

29	Consider criteria for dedicated lanes	OEMs, ADS providers, fleet operators	Money, time, clarification of legal consequences	Medium term
30	Inventory of (critical) bridges, their bearing capacity and condition; Research and studies on the effects of e.g. platoons	OEMs, ADS providers, research and academia	Money	Medium term **Action Source: MANTRA**
31	Research into real-time lane management and role of authorities (possibility to allocate lanes to automated vehicles in certain circumstances or on certain times).	OEMs, ADS providers, service providers	Money, Cooperation	Medium term **Action Source: MANTRA**

<u>Road authority/operator process</u>

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
32	Lifecycle models for pavements possibly to be adapted because of rutting	Contractors, research and academia	Money	Medium term
33	Processes to ensure landmarks will be consistently visible	ADS providers, contractors	Money	Medium term

<u>Organisation, role, processes</u>

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
34*	Clarification of roles of stakeholders to ensure industry has incentives to design automated driving system with road safety as a key	OEMs, ADS providers, vehicle authorisation bodies	Cooperation	Short term
35	Determine road authority role in vehicle type approval	Vehicle approval body, ministries, EC	Cooperation	Short term **Action source: RWS roadmap**

36	Include smart mobility in traditional road decision process	Ministries, Other experts	Cooperation	Short term **Action source: RWS roadmap**
37	Accountability in case of mistakes or conflicting interpretation. Pilots to investigate new role models (option to cover risks from a commercial cost/benefit perspective)	OEMS, ADS providers, HD map providers, ministries, insurance companies, legal experts	Money, clarification of legal consequences	Short term **Action Source: MANTRA**
38	Consider role of own digital maps for HD maps in general	HD map providers, OEMs, service providers	clarification of legal consequences	Short term
39	Legal framework to allow researchers to analyse and audit while reasonably preserving industry interests	OEMs, ADS providers, HD map providers, service providers, mobile network operators, research and academia	clarification of legal consequences	Short term
40	Cybersecurity issues, explore risk mitigation in cooperation with other AV-related stakeholders	OEMs, ADS providers, HD map providers, service providers, cyber security experts	Cooperation	Short term **Action Source: MANTRA**
41	Prepare for ODD requirements discussion in winter conditions	OEMs, ADS providers	Cooperation, clarification of legal consequences	Medium term
42	Remote operation centres (run by fleet owners) including questions of "roaming" / cooperation between operation centres. Preparation of legal framework and piloting of some operation	OEMs, fleet providers, service providers, mobile network operators, other experts	Cooperation	Medium term **Action Source: MANTRA**
43	Consider role of road authorities in ODD management	OEMs, ADS providers	Cooperation, clarification of legal consequences	Long term

5.3.3. COST AND BENEFITS

No	Action/recommendation in short	Other stakeholders	Resources needed	Timing
44*	Launch pilots that include societal focus to get a better understanding of costs and benefits	Industry, research and academia.	Include in procurement criteria if possible	Short term
45*	Find business models considering that the actors benefitting might not be the same as the one bearing the costs.	All industry stakeholders, ministries, EC, research and academia	Innovation and creativity, cooperation	Medium term

5.3.4. CONSULTATIONS

Each participating country was asked to organise a national meeting to discuss the priorities in the actions/recommendations, the reasons behind, the of infrastructure, cost & benefits. The outcome of the meetings is summarised here, a more detailed description can be found in appendix 2. The results are already processed in the table above.

Out of the 45 actions, 14 got the most priority votes overall. They are marked with an asteriks* in the table above.

While considering the actions, authorities need to see if they want to be a front runner, possibly getting benefits the quickest, or await industry or other countries initiatives. The actions/recommendations can also be seen as research questions for the coming years, as part of the strategy development. Some actions be already be ongoing in countries.

Only after we have enough knowledge and facts to support decision-making, we can make actual investments to facilitate automated driving. This is not the time to start any investment programme. In general, the actions providing additional information and knowledge are considered to be very important in this phase when there are so many uncertainties. Many of the digital data provision actions are no-regret, they are valuable in any scenario. Prerequisite is a high quality internal process ensuring high quality data.

There are major differences between EU member states in the roles and operational models of the different stakeholders. Therefore, agreements on solutions for many deployment and operation related issues will be much more difficult than agreement on technology issues.

Regarding assessing best solution for ODD endings and minimal risk manoeuvres: authorities should be in the lead to define requirements towards vehicles, they do not want to be confronted with (possibly different) solutions by OEMs for this. On the other hand, it would be very useful for the road operator to learn and understand where the ODDs often terminate in order to prepare for multiple events of minimum risk manoeuvres, and consider actions to prevent ODD terminations if possible.

Regarding costs and benefits: pilots and trials with accompanying research actions are crucial to reduce the uncertainties. It is typical for infrastructure investments by the public sector that they mainly bring benefits for other (private) stakeholders. The key target here is fairness so that all stakeholders and citizens are treated equally. The public actors are willing to provide support to socially beneficial services in their initial phases to get the service going, but quite reluctant to stay as a supporter for the long term.

5.3.5. CONCLUSION

The list of action and recommendations above is a selection, with a focus on the ones that are applicable for the main topics of this document: infrastructure and cost-benefit. Many of the actions concern topics that minimally need to addressed by road authorities/operators: What will be our strategy? What is our role? How do our decision-makers see this? Regarding timing, most actions are for the medium term. Actually, for many actions different phases can be distinguished: research, considering the option, making choices, deployment, etcetera. This means that thinking may need to start on the short term, while actual deployment (if chosen for) could take place on the long term. Goal is to stand prepared for automated driving, have influence on the development and to reap the potential benefits as soon as possible.

5.4. Way ahead

This paragraph describes the way forward for this roadmap document as such. The document will be finalised and officially delivered in Q4 2020. The recommendations and actions from this document should be taken further by the road authorities and other stakeholders. Especially the road authorities participating in EU EIP can use the recommendations for their actions plans. In doing so, the recommendations and actions will be refined and updated by these stakeholders in the coming years.

The conversation and joined action should definitely continue, as the recommendations in this document clearly show. However, it would be advisable to converge the large number of roadmap activities in Europe towards a smaller number of dedicated work streams. One of those dedicated activities would be the road authority perspective on CCAM. A possible EU EIP follow-up project should definitely link to ongoing activities in CEDR and especially the EC's CCAM work, where the conversation on automated driving will continue.

6. Conclusions & Recommendations

6.1. General Conclusions

Mobility of people and goods is a fundamental facilitating aspect for our society. Many stakeholders are working to make it as safe, efficient and clean as possible, from a business, scientific or governmental perspective. One of the most prominent developments is the automation of road transport.

Stakeholders in mobility need to consider their position and potential benefits of automation. What is their vision, desired direction of development? What are their interests? What options and power do they have to steer the development? What can and should they practically do to prepare? In this document, we looked at these questions mainly from the point of view of the road authorities and operators – since they are core contributors to the EU EIP project. They have a long-standing role and responsibility in road infrastructure planning, development, construction and management. Our question is: What impact does automation have for road authorities and operators?

Stakeholders have already been considering their position on automation for some time, on different levels and in several initiatives and national and EU-funded project. This is a continuous effort since the field of automation is constantly evolving. This roadmap document is part of this continuous effort and focuses on the following topics:

- impact of connected and highly automated driving on and role of physical and digital infrastructure, with a specific focus on the concept of Operational Design Domain (ODD);
- cost and benefits of automation for road authorities and operators.

For both topics, the document focuses on findings and efforts so far, and sets out a direction for future work. The role of the digital infrastructure will evidently grow considerably and digital twins will be increasingly important. There is a need to discuss the concept of digital twins and their required properties among the stakeholders to agree on a common view on digital twins and their development, operation and management needs.

The focus on the role of road authorities and operators does not mean other stakeholders are out of scope. Roles in this field cannot be considered in isolation anyway. A stakeholder consultation process was part of the preparation work for this document, so various stakeholders' views on future developments and roles are certainly part of the process.

The process has led to a wide range of information and insights, and to a list of actions and recommendations. Many of the actions concern topics that at least need to addressed by road authorities/operators: What will be our strategy? What is our role? How to safeguard the safe, efficient and clean performance of the road networks especially in mixed traffic (of both highly automated and human-operated vehicles)? How do our decision-makers see this?

The emphasis is clearly in learning more about the developments and evolution of higher level (SAE 3-4) automated driving including the related ODD requirements. It is premature to commence deployments unless road authorities and operators are certain that the solutions invested in will not become obsolete in the short term. This highlights the importance of research, field trials, demonstrators, and deployment pilots, but also structured dialogue between the road authorities/operators and the automated driving industry. Some of the short-term actions, however, can be carried out with no regrets as they will benefit the road network operations already today and involving human-operated vehicles. Such relate to, for instance, provision of data in digital form, digitalisation of key processes, implementing cybersecurity, and provision of connectivity of the physical and digital infrastructure.

Regarding timing, most actions are for the medium term. Actually, for many actions different phases can be distinguished: research, considering the options, making choices, deployment, etcetera. This means that thinking may need to start on the short term, while actual deployment (if chosen for) could take place on the long term. Goal is to be prepared for automated driving, have influence on the development so that road network operation does not suffer but rather improves, avoid excessive investments in vain, and to reap the potential benefits as soon as possible.

6.2. Recommendations

The recommendations and actions from this document should be taken further by the road authorities and other stakeholders. Especially the road authorities and operators participating in EU EIP are expected to consider the recommendations when developing their actions plans. In doing so, the recommendations and actions will be refined and updated by these stakeholders in the coming years.

An important point of attention that came out of the final workshop of the project is the involvement of end users. Their views and actions (awareness of developments, acceptance of technologies, what vehicles they buy, how they use them, etcetera) are fundamental to the developments. Their role should not be underestimated or viewed purely from a theoretical perspective by mobility experts. Their inclusion in the design and development processes should be carefully considered in order to make it as useful and easy as possible, despite the challenges of accomplishing this in practice.

The conversation and joined action should definitely continue among the road authorities and operators as well as among the key stakeholders utilising platforms such as the CCAM platform. However, it would be advisable to converge the large number of roadmap activities in Europe towards a smaller number of dedicated work streams. One of those dedicated activities would be the road authority perspective on CCAM. A possible EU EIP follow-up project should definitely link to ongoing activities in CEDR and ASECAP, and especially the EC's CCAM related actions and platforms, where the conversation and cooperation on automated driving will continue.

It is advisable to update this roadmap document parallel to the ongoing technology development as well as stakeholder liaison and interaction . New developments, insights, multistakeholder agreements, and policies should be included into the document so it can continue to set out a direction for future work. An update frequency of once every 2 years could be valuable. It is to be determined how the updates can be organised, the most obvious way would be through a possible follow up to the EU-EIP project.

The actions and recommendations from this document, with their variance in timing, clearly show that research and deployment should go hand in hand to solve the challenges of the future. While the CCAM partnership will focus on the research activities under the umbrella of Horizon Europe, it is equally important to include automated driving in the deployment focussed CEF2 programme. This should in the first phase focus on deployment pilots as well as deploying digital infrastructure supporting both connected automated and human-operated vehicles. In the second phase, the focus should move towards deployment on the CEF corridors and networks. The CEF2 programme should also host deployment related harmonisation actions to ensure that the physical, digital and communication infrastructure solutions will provide seamless cross-border connected and automated mobility in Europe and related road network operation solutions including traffic management.

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Appendix: 1. Country profiles

United Kingdom

The Emerging Technology Landscape

Judging by most analysis, changes to road transport will be driven by innovation across the following five areas: 1) Digital connectivity between vehicles and their surrounding environment, 2) Increasing degrees of vehicle automation, 3) Proliferation of electric vehicles, 4) Emergence of new mobility models, such as 'mobility as a service', and 5) Increased creation and utilisation of data. Any attempt to predict emerging innovations will be speculative in nature and is therefore likely to change over time as our understanding improves. The effects of new roads technology will also be shaped by wider changes in society and broader currents of technological development across many other sectors, which add further complexity to the question of why and how we will travel in the future.

Policy

Ultimately, future roads technology and mobility trends are well integrated into government policy, as demonstrated by ongoing investment in innovation through government as well as the recently announced Future of Mobility 'grand challenge' identified in the Government's Industrial Strategy. The potential for a road's revolution is one of the key considerations of the National Infrastructure Commission's assessment of future infrastructure needs. These initiatives mean the UK has one of the most active and forward-looking policies in the world for advancing roads technology. However, we are only beginning to understand the benefits, needs and consequences of emerging innovation and policy must adapt continuously if it is to stay up to date. We also recognise the difficulties and inherent risks in trying to predict the future: it is not government's role to select winning technologies, but instead to create the conditions in which innovation can prosper.

We therefore propose that RIS2 develops an approach based on three pillars in preparing for new technology:

- Continued research and trials
- Key structural commitments supporting technology
- Allowing for flexible decision making in the future

Ongoing Initiatives

The development of connected vehicles is being driven globally by a combination of industry, academia and government. The UK is engaged in many trials and research projects which should show the likely scale of 'digital demand' created by connected vehicles over time across different road environments, as well as the optimal enabling technologies and likely quantum of enabling infrastructure.

Government is encouraging on-road trials of automated vehicles in the UK and has made support for the autonomous sector a key part of one of the 'grand challenges' in its Industrial Strategy.

Trialling any level of automated vehicle technology is possible on any UK road if carried out in line with UK law. Trialling organisations do not need to obtain permits or pay surety bonds when conducting trials in the UK. As part of complying with the law, they will need to ensure that they have a driver or operator, in or out of the vehicle, who is ready, able, and willing to resume control of the vehicle; a roadworthy vehicle; and appropriate insurance in place.

Key examples include:

- Exploit data and Smart Infrastructure
- Electric vehicles and supporting infrastructure
- Future of Urban Mobility Strategy
- The MERIDIAN co-ordination hub for connected and autonomous vehicles (CAV)
- Improved traffic management CHARM
- Increased road space utilisation
- Truck platooning trials.

Romania

Current policy and legislation

Digitalization in administration and economy is a top priority for Romanian government. For the transport field, this translates in support for ITS for all modes at national level and support for ITS/smart mobility as part of Smart City initiatives at regional level.

The major investments are managed by the Ministry of Transport and Communications; and Ministry of Regional Development mainly thru structural funds and programmes such as:

- Operational Programme Large Infrastructures
- Regional Development Operational Programme

The ITS Directive 2010/40/EU was transposed in Romanian legislation by Government Ordinance in 2012 and there are several strategic documents related to the development of ITS and Smart Cities:

- National Transport Masterplan
- National Strategy for Sustainable Development up to 2030

- National Strategy for multimodal transport
- National Strategy for Digital Agenda
- National Strategy for Sustainable Transport up to 2030
- Sustainable Urban Mobility Plans in major cities

The National Motorway Company is responsible for implementing and operating ITS for all national roads while implementations in cities are under the responsibility of the municipalities.

The National Motorway Company has an internal decision which demands that all new motorways are built with basic ITS infrastructure: communication network, loops and cameras, VMS.

In the last years cities have been developing smart mobility infrastructure and solutions such as communication networks, traffic and public transport management systems, integrated e-ticketing and electric/alternative fuels public transport fleets.

Also, the telecom operators in Romania (Vodafone, Orange, Telekom, Digi Romania) are starting to be interested in supporting and deploying smart transport solutions.

Roadmap & strategy

The National Motorway Company and municipalities are committed to further develop smart mobility, physical and digital infrastructure harmonized and aligned with European implementations. The focus topics to achieve this are:

- implement ITS on existing national roads
- use open platforms that make it easier to introduce new technologies and data sources
- develop regional TMCs and built a national TMC
- pilot smart mobility solutions and technologies

Ongoing initiatives

Romania is participating in the European Commission's CCAM platform and the Motorway Company has been/is involved in European projects for harmonization and deployment like EIP, EIP+, EU EIP, Crocodile.

The implementation of the National Access Point is ongoing, and The Motorway Company is also interested in piloting C-ROADS or other project proposals dealing with automated vehicles and C-ITS.

Several cities are implementing smart city solutions and Cluj-Napoca, one of the most advanced in this field, will be this year the first to pilot driverless automated shuttles.

Spain

Current policy and legislation

The government of Spain is working to promote the connected and autonomous vehicle with the aim of helping to achieve the Vision Zero of deaths, injuries, emissions and congestions.

The objective is to provide a more personalized information service to citizens, adapting it to the new challenges, demands and opportunities that the connected vehicle and autonomous driving bring with them.

In this context, in 2015, the Directorate General for Traffic approved the instruction 15/V-113: Authorization to conduct tests or research trials of automated vehicles on roads open to general traffic, aimed at regulating the granting of special authorizations for the performance of tests and research trials, carried out with autonomous vehicles on roads open to general traffic.

More recently, in 2019, the instruction 19/V-136 was published: Procedure for the designation of Technology Recognition Centres and for the certification of ADAS Aftermarket systems. This instruction aims to establish the technical criteria that allow the certification of the functionalities of ADAS Aftermarket systems, sets the procedure for the designation of Technology Recognition Centres authorized to perform these certifications and determines the technological requirements that these centres must meet.

Roadmap & strategy

The future Road Safety Strategy 2021-2030 is a strategic issue in terms of mobility, contributing to making Spanish roads more reliable and making Spain even safer in terms of mobility. It is an initiative that was created with the purpose of reducing the number of deaths and serious injuries by 50%. Based on this central idea, the government is already working on a plan for safe, sustainable and connected mobility that aims to be deployed based on strategic guidelines that address current and future challenges related to mobility:

- Mobility for all. This concept is linked to providing mobility to all people in both urban and rural areas.
- Safety. It is the substrate on which any transport service must be implemented. It is a question of guaranteeing the necessary investments for the conservation of the infrastructures, of introducing massively the technology for the management of the safety and of facing the challenges of the future as the cyber security.
- Intelligent mobility. Implementation of technologies such as 5G, the internet of things, robotics, big data and block chain to keep moving forward.
- Low-emission mobility. It is based on the need to manage services, infrastructure and modes of transport as efficiently as possible.

- Intermodal and intelligent logistics chains. This point will address all the challenges related to digitisation and mobility as a service.

Ongoing initiatives

Currently in Spain, work is being carried out on various projects at a national and international level in relation to connected and autonomous driving.

At the European level, the single CCAM platform brings together a group of experts in cooperative, connected, automated and autonomous mobility to provide advice and support to the European Commission in the area of testing and pre-deployment activities for CCAM over the next three years.

For its part, the INFRAMIX project is working to develop a hybrid test system by coupling infrastructure elements and vehicles on real roads (or test tracks) with a virtual traffic environment that includes representative mixed traffic situations within the three predefined scenarios: Dynamic Lane Assignment to automated driving, Roadworks zones and Bottlenecks.

At a national level, the C-ROADS Spain project will enable the development and deployment of V2X and V2V communications over more than 12,500 km of national network using hybrid ITS-G5 and cellular (3G and 4G/LTE) communication technologies.

Within the project, the DGT 3.0 pilot project should be highlighted, which proposes the use of a technological platform that allows different road users to be connected in real time, offering them real-time traffic information at all times and thus enabling safer and more intelligent mobility.

The Netherlands

Current policy and legislation

The Dutch government is looking at new technologies to solve challenges in the area of transport, the environment and safety. The government is working together with the private sector to develop self-driving vehicles, and to improve in-car traffic information for drivers. Goal is to reduce congestion and CO_2 emissions, and improve road safety. Data is vitally important in this, so a lot of work is being done to improve data transmission and data quality.

The Netherlands wants to take the lead in new initiatives like the Internet of Things, smart cities and connectivity. The aim is to make Smart Mobility possible on a larger scale. By establishing the Netherlands as a country for testing automated cars and Intelligent Transport Systems, the minister wants to make the Netherlands a fertile breeding ground for this kind of innovation and facilitate these developments. A coordinated approach at a European level and closer cooperation between governments and stakeholders is required to allow these innovative systems to become available on the market.

The Ministry of Infrastructure and Water management ('I&W') has opened the public roads to large-scale tests with self-driving passenger cars and trucks. The Dutch cabinet has adopted a bill which makes it possible to conduct experiments with self-driving vehicles without a driver being physically present in the vehicle. This 'Experimenteerwet zelfrijdende auto' (law governing the experimental use of self-driving vehicles) removes legal impediments.

Roadmap & strategy

An important part of the strategy is Learning by doing; Gaining practical experience with new systems, will allow the government to keep pace with these advancements. The most recent National policy letter on smart mobility from the Ministry sets out four priorities: Promote the safe use of ADAS, Sensible & safe introduction of a new generation of vehicles, Future-proof infrastructure and road management, and Opportunities in data exchange and connectivity.

For national road authority Rijkswaterstaat smart mobility is one of priority areas as well, on the physical & digital infrastructure side of this Rijkswaterstaat is working on:

- future-proof roadside systems: open platforms that make it easier to introduce new technologies and data sources.
- automation in traffic management centres: open and scalable TMC software, smart management of hard shoulder running.
- future-proof building & maintenance: include smart mobility options in procedures for existing and new infrastructure.
- infrastructure ready for self-driving: communication technology, assess current road design requirements, common test agenda with other road authorities.

Ongoing initiatives

The Netherlands is participating in several national and international initiatives on automation. The European Commission's CCAM platform and national road authority cooperation CEDR focus on the strategic side, while the project ARCADE looks at road maps and knowledge and EU EIP on the tactical and operational side.

On national level, there is a close cooperation between national, regional and local road authorities ('LVMB'). They did an analysis of road design elements, and the impact of automation on each of these, taking in account notions around mixed traffic and evolution of smart vehicle capabilities.

Regarding communication (cooperative ITS), projects like the corridor Rotterdam-Vienna, C-Roads/InterCor have been running for a while now. There are currently plans for a national follow up project (C-ITS next) focusing on end of queue warning on roads with overhead signals. And lastly, the Netherlands Vehicle Authority RDW, the Netherlands

Driver Exam Authority CBR and Rijkswaterstaat initiated the 'Software Driving License Project': a collaboration of stakeholders who want to contribute to an international standard for licensing of intelligent vehicle operating systems.

Sweden

Current policy and legislation

The Swedish government has put in place necessary legislations, allowing tests of self-driving technologies on public roads. Application for testing of automated vehicles on public roads need to be submitted to the Transport Agency which is authorized to administrate and approve applications.

Moreover, the necessary adaptation of the national legislations, are already been identified, in order to allow self-driving vehicles on public roads.

Sweden encourages a coordinated approach at European level and a closer cooperation between governments and stakeholders to allow innovative mobility/transport solutions to be introduced on the market.

Sweden like many other countries in Europe has the ambition to be the forefront for development of automated mobility solutions in Europe. This is obvious as Sweden has a strong automotive and telecom industry together with a culture for cooperation between academia, industry and public sector, which are the main components needed to design and implement large- scale demonstrations.

Roadmap & strategy

Trafikverket established a road map in 2018 with the following main objectives;

- Increased knowledge about the effect of automation
- Efficient use of available road capacity
- Sustainable and safe transport system through digitalization
- New supporting tools for the planning process

The above objectives are summarized in clusters with the following prioritized focus areas;

- Behavior and acceptance
- Road infrastructure
- Data, IT- and communication infrastructure
- Vehicle development
- Laws and regulatory frameworks
- Business models and collaboration among actors

The short- term activities at the Swedish transport administration are;

- Dialogue on identifying transportation challenges together with municipalities, and discussing about possibilities with vehicle industry and other relevant actors, such as; operators, telecom, etc…
- Producing procurement documents for the implementation of new mobility/transport solutions. Necessary inputs from industry are identified as the key elements for such an innovation procurement documents
- Together with Swedish Transport Agency assess the feasibility of such a procurement from a legislative perspective.

The above procedures are expected to result in validation of the procured solutions, as well as facilitate stepwise introduction in a large scale. This systematic approach is assumed to generate the needed knowledge on various possibilities for developing the future road infrastructure.

Ongoing initiatives

The Swedish government has established a new instrument for addressing complex areas with huge potential to come up with sustainable solutions to challenges in our society,

One are is the opportunities and challenges with the next generation mobility system for people and goods. This is requiring close cooperation among several stakeholders to succeed. Drive Sweden was awarded a contract to address this area. The work is divided into five thematic areas with several projects in each area.

- Society planning
- Digital infrastructure
- Business models
- Policy development
- Public engagement

Sweden is also participating in several international initiatives on automation. Regarding communication, projects like NordicWay has been running since 2015 are exploring the use of existing mobile network for V2V and V2X communication. During the upcoming years NordicWay are looking into making the Nordic countries a forerunner when it comes to geofencing and digital traffic regulations.

Germany

Current policy and legislation

With the notable standing of the automotive industry and Autobahn network, Germany is actively working on addressing the ongoing shifts in mobility, shaped by innovations in technology but also the arising challenges brought forth by environmental concerns. Under the overarching objective of increasing the safety and efficiency of traffic and also pursuing environmentally friendlier practices, Intelligent Transport Systems (ITS) have become an indispensable element of transportation policies in Germany. The foundation was laid in 2010, when the European Parliament adopted a directive on the deployment of ITS in the field of road transport, including also interfaces with other modes of transport. Based on this, the German Federal Ministry of Transport and Digital Infrastructure in coordination with federal ministries, states, local authorities, industry and trade associations, took initiative to establish the framework for ITS on a national level, the ITS Action Plan.

Roadmap & strategy

The German National ITS Action Plan, for its current strategy, is pursuing the development of ITS measures on three different fronts. The first focal point is data and its optimized use in road, traffic and transport. The increasing utilization of data, including its seamless accessibility and high-level quality, is a central prerequisite for not only successful traffic control and provision of traffic information but almost all further ITS developments. The second focal point encompasses the cohesive coordination of ITS services for traffic management and traffic information. This includes establishing a framework, which can consolidate the employment of ITS services across various areas of activities, and defining required interfaces. The third focal point follows the concrete and focused implementation of ITS applications aimed at improving traffic efficiency, road safety and environmental performance.

Initiatives in ITS and Automation

Advancements in cooperative, connected and automated mobility require efforts on a national as well as international scale, in order to not only progress but also harmonize efforts in ITS technologies.

On a European level, Germany is involved in the Rotterdam-Frankfurt-Vienna Cooperative ITS Corridor. This project is playing a major role in establishing cooperative traffic infrastructure and thus laying the foundation for the operational rollout of V2X technologies.

C-ROADS is launching and harmonising various Cooperative Intelligent Transportation System (C-ITS) services across Europe. A significant feature of this project is the interoperable and seamless cross-border deployment of the technologies.

Notable national initiatives, which have been able to lay considerable groundwork in the field of automation, are the projects aFAS and KoHAF. The project aFAS successfully developed and tested the first automated, driverless, safety vehicle for roadworks on motorways.

KoHAF developed and tested highly automated driving for speeds up to 130km/h. This was, in large, facilitated through communication via a backend safety server which was able to provide enriched data through a digital map. The current project IMAGinE is developing and evaluating intelligent maneuver automations for the real-time prevention of hazardous traffic scenarios. These projects were realised on the DRIVE test field in and around the city of Frankfurt am Main. This test track is operated by the state of Hessen and has been established to provide dedicated research grounds and conditions for intelligent traffic systems.

Finland

Current policy and legislation

Finland has recently introduced major legislative changes that affect greatly the implementation of new transport services and traffic automation. The national Act on Transport Services has been prepared and confirmed in three phases; the last one came into force on 1st of April 2019. The goal of the new act is to bring together legislation on transport markets. The aim of the legislative reform is to provide the users with better transport services and to increase freedom of choice in the transport market. The Act will allow the provision of new type of smooth travel chains consisting of different transport modes (e.g. Mobility as a Service (MaaS) services). The main changes to the national legislation have been

- streamlining the regulation and reducing bureaucracy
- uniform handling of different travel modes
- handling of goods and person transport as services, that can be combined as travel chains
- increased interoperability of ticketing and payment interfaces
- improvement of digital transport services
- centralisation of all licenses regarding transport service operation and vehicles in one registry
- social requirements of road transport
- professional license of heavy goods vehicle operation.

Roadmap & strategy

Finland wants to be one of the leading countries in the development, deployment and use of automated transport (air, road, rail and maritime) and in highly automated vehicles.

Finnish transport authorities have closely examined all legislation and regulations related to automated driving in Finland. The conclusion is that the current Finnish legislation (including adherence to international conventions) allows for the use and testing of self-driving vehicles on public roads.

This means that automated vehicles can easily be tested in Finland using test plate certificates. The first test plate certificates were given out in July 2016, and up until September 2020, a total of around 20 certificates have been given out to approximately 10 different organizations for one or several vehicles each.

Currently the Finnish Ministry of Transport and Communications is reviewing what type of legislative amendments will be required to support and allow transport automation and resulting benefits: increased safety with reductions in accidents caused by human error, more efficient traffic control services, and emissions reduction by means of information

To promote automated driving, the Ministry and other road and transport authorities have developed a roadmap for automated driving. The roadmap “A roadmap for developing automation and robotics in transport sector 2017-2019 was published in 2017. The key actions for the entire administrative branch include exerting influence on the international regulation of different transport modes, enabling experimentations, developing an interoperable infrastructure and devices for transport automation, introducing 5G network technology, increasing the amount, quality and usage of transport data, and improving the quality of satellite positioning.

Ongoing initiatives

Finland is actively participating in several European initiatives and platforms on automation, including the European Commission’s CCAM platform and European transport ministers’ HLM activities including the Data task force.

Transport is seen as a strategic innovation area for research and piloting and especially because of opportunities in smart mobility. In Finland, the backbone is the National Transport Growth Programme defining the strategy for the transport research. Since 2016 Finland has been running a large number of initiatives in automation, including research and innovation projects are supported by CEF and Horizon 2020 programmes as well as Regional Development Funds. There are also many nationally funded research and innovation projects. A number of pilots and demonstrations have taken place or are planned in major cities Helsinki, Espoo, Tampere, Turku and Oulu.

The key projects are NordicWay (1, 2 and 3) developing hybrid C-ITS services since 2015, the CEDR-funded MANTRA looking at the impact of highly automated driving on the road authorities and core business, and Arctic Challenge (a part of the NordicWay 2), which was studying the feasibility of automated driving in severe winter conditions. Finnish stakeholders have actively developed the facilities and expertise in the evaluation of automated driving and its impacts.

The SOHJOA project brought small automated electric bus piloting services in three cities Helsinki, in Espoo and in Tampere during 2016-2018. The national project ROBUSTA developed various topics related to automation in transport. The ongoing FABULOS project seeks new solutions and technologies including automated buses to prepare cities for future mobility, and finally the just started SHOW project aims to support the deployment of shared, connected and electrified automation in urban transport, with a demonstration in Tampere.

Currently the Finnish Transport Infrastructure Agency is starting an inventory of the their main road network including TEN-T with regard its readiness for highly automated driving.

Finland has also worked to ensure transition to the 5G world with its huge potential to maximize communications reliability so important to connected and highly automated driving. In the period 2017 – 2020 Finnish partners have actively initiated and participated in a number of 5G projects including 5G DRIVE, 5G SAFE and 5G-SAFE-PLUS.

Appendix: 2. Stakeholder workshops

For this roadmap, stakeholders were consulted in several ways. The main consultations are listed below – the outcomes of these events are included in the main text of this roadmap document.

Athens, November 2018

In November 2018, a joint EU EIP 4.2 & L3Pilot workshop took place in Athens discussing the Impacts of automated driving and how to maximize the benefits. The L3pilot project unites 34 partners: OEMs, suppliers, research, SMEs, insurers, one authority and one user group. They perform large-scale piloting of automated driving with developed SAE Level 3 and Level 4 functions in passenger cars.

All relevant stakeholders from both EIP 4.2 and L3Pilot were invited to this Workshop, and it attracted representatives from automotive OEMs, equipment suppliers, telecom industry, road operators, local and regional authorities, governments and research institutes, about 80 in total.

For more details see https://eip.its-platform.eu/highlights/impacts-automated-driving-how-maximize-benefits-workshop-summary-0

Torino, October 2019

In October 2019, the project organized a workshop in Torino around the theme Operational Design Domain, and aforementioned common terminology. The workshop welcomed everyone involved in shaping innovation in the automated driving. Overall, the Workshop attracted in all 37 participants with 15 from industry and the private sector, 17 from public sector and road operators, and 5 representing academia and research.

For more details see https://its.sina.co.it/news/index.php/it/home/8116345-proceedings

Presentations to the CCAM platform

The Cooperative, Connected, Automated and Autonomous Mobility (CCAM) Single Platform consists of an informal group of private and public stakeholders. The group includes one hundred experts in the field of CCAM from twenty-five member states, started in 2019 for the duration of three years.

EU EIP 4.2 first presented there in January 2020, regarding the process for the EU EIP 4.2 roadmap. It concerned a meeting of working group (WG) 3 of the platform, working on Physical & Digital Infrastructure.

A second presentation to CCAM WG3 was done on June 29 2020, in a virtual meeting. Comments included the urban side of the topic, which is largely out of scope because of focus on the TEN-T network, and to consider OEM perspectives as raised in publications by ACEA and the L3pilot. WG3 is working on a framework (matrix) with infrastructure attributes to guide discussions and works towards a deliverable at the end of 2020. This will include recommendations for follow up. The EU-EIP project can provide input for this deliverable.

National consultations

Set up of consultation

Each participating country was asked to organise a national meeting to discuss:

- the priorities in the actions/recommendations
- why are these priority actions? Can you elaborate on it, what would it mean in practice, what and who would you need, what are open issues, etcetera?
- what additional actions / recommendations would you suggest?
- any other comments attendees to the actions / recommendations or other parts of the roadmap?
- the following questions, if time permitted:
    - opinion on limiting the dependence on physical infrastructure because of the high cost involved.
    - Considerations on ODD endings and ODD management
    - Are cost & benefits part of discussions on CAD in your organization, how are you dealing with the uncertainties and how do you see a situation where government investments mainly bring benefits for other (private) stakeholders?

Outcome

The summarised outcome of the meetings is:

- Suggestion to do a better structuring of the actions/recommendations, and to combine some similar one, for easier review - *suggestion is processed in current version of document.*
- There are differences in level of detail of actions/recommendations, some are very general and some very detailed. - *suggestion is processed in current version of document.*
- Some actions may already be ongoing in a country. In general, countries/authorities/operators need to determine if they want to be a front runner,

possibly getting benefits the quickest, or wait for the industry that may look to large countries first or develop based on the less developed regions.

- The actions/recommendations can also be seen as research questions for the coming years, as part of the strategy development.
- Many of the digital data provision actions are no-regret, they are valuable in any scenario. Prerequisite is a high quality internal process ensuring high quality data.
- The human / road user side could be added to the list. One can think of many technological solutions but human road users will have to deal with them.
- The actions that received relative high priority in the countries are:
    - Supply real-time information on road status and regulations (An important enabler with multiple benefits, Quality assured information is the key to everything)
    - Assess best solution for ODD end (many minimal risk manoeuvres)
    - Sustainable, long term digital service provision
    - Appropriate quality assurance methods and processes for data provision
    - Develop concept of cooperative traffic management
    - Launch pilots that include societal focus to get a better understanding of costs and benefits (Gradual evolvement, small effects in the beginning and primarily costs, in the long run more benefits)
    - Common framework of definitions for infrastructure requirements discussion
    - Consider more consistency in road network and less particularities
    - Implement machine readability in road marking standards
    - Set up digital twin of transport system
    - Develop investment scenarios for road side systems vs smart vehicles. What is needed in light of evolution of automated vehicles?
    - Find business models considering that the actors benefitting might not be the same as the one bearing the costs.
    - Clarification of roles of stakeholders to ensure industry has incentives to design automated driving system with road safety as a key
    - Use of automated vehicles to monitor the performance of road works management
- In general, the actions providing additional information and knowledge about the ODD and infrastructure requirements, impacts, benefits, costs, acceptance, operation, performance, etc. are considered to be very important in this phase when there are so many uncertainties.
- Only after we have enough knowledge and facts to support decision-making, we can make actual investments to facilitate automated driving. This is not the time

to start any investment programme. There may be no-regret actions, like making sure the roads are in line with current design guidelines (for road safety), this would offer a clear framework towards other stakeholders: this is what we are offering.

- Short-term actions are naturally more in priority than the medium and long-term actions.
- The role of authorities and road operators in the development and update of HD maps needs to be investigated thoroughly. Road operators should have real-time information of their road networks, and this data should be made available to HD map providers and/or service providers. Any changes in the data should be pushed immediately to the map and service providers. Legal status of digital information should be arranged. HD maps and digital twins are closely related, and there exist many different interpretations of both of these concepts. It would be very useful to agree on common definitions on both concepts and their contents.
- Regarding adaptation of ramps: at first, longer ramps may be needed, but as automated cars become more advanced and cooperative they may need less space. In general the question is: do we look towards infrastructure to accommodate or do we add requirements in the type approval?
- The following actions/recommendations received some critical comments:
    - Invest in roadside equipment where needed and others do not: This could be the case when the roadside equipment is regarded as necessary for the road operator’s own purposes, but not otherwise. Further research needed first.
    - Processes to ensure landmarks will be consistently visible: the need for the landmarks and their additional equipment as well as the responsible organisation must be determined first before making such a demand.
    - Network of land stations for satellite positioning: provision of land stations for GNSS is not the task of the road operators in many countries
- Action: Research into real-time lane management and role of authorities should be clarified. - *suggestion is processed in current version of document.*

- There are major differences between EU member states in the roles and operational models of the different stakeholders. Therefore, agreements on solutions for many deployment and operation related issues will be much more difficult than agreement on technology issues. The road authority/operator is not the main stakeholder in many of the 47 actions on the national level in all countries.
- The way forward would be 1) to start with trials and pilots, research and studies to identify the best solutions, 2) to standardise these solutions, and 3) to deploy the standardised solutions. No standardising should be done without comprehensive agreement between stakeholders on which is the best solution. It is important to address cybersecurity aspects in the process.

- The basic idea of avoiding high-cost investments in the adaptation of the physical infrastructure is accepted. It was pointed out that also digital infrastructure may be costly to invest, for instance communication infrastructure.
- It would be good that the roads could “tell” the automated vehicle and the driver for instance the ISAD level and related infrastructure attributes provided on the road. This is the “self-explaining road” concept for automated driving.
- Regarding assessing best solution for ODD endings and minimal risk manoeuvres: authorities should be in the lead to define requirements towards vehicles, they do not want to be confronted with (possibly different) solutions by OEMs for this. Cooperation with OEMs is crucial, e.g. otherwise authorities may assess many scenarios that are not realistic in the first place.
  It is obvious that stopping is not a safe minimum risk manoeuvre on most roads and in most cases. Hence such safe solutions must be found.
- According to people in different countries, the management of ODDs must be the responsibility of the vehicle manufacturer/automated driving system provider. This is key to the accountability and liability of the automated vehicle provider. Naturally, the road operator can provide information affecting the ODD to the vehicle and/or the automated vehicle provider, but this is to be considered as “hint” information only, with no liability transfer to the road operator. In any case, it would be a very difficult task to take on as road authority, you would need to be agile towards several OEM products that are constantly being updated.
- On the other hand, it would be very useful for the road operator to learn and understand where the ODDs often terminate in order to a) prepare for multiple events of minimum risk manoeuvres, and b) consider actions to prevent ODD terminations if possible. Data from vehicles is very interesting for road authorities in general, for their own processes. The other way around, reliable information from the infrastructure could be used to decide if a manoeuvre can be performed safely.
- The owner or occupant of a highly automated vehicle must be aware of the ODD capabilities of the vehicle. This applies to when buying the vehicle as a new one, but also when buying a used vehicle, and when the automated vehicle provider updates the vehicle so that the ODD is changed.
- Regarding costs and benefits: So far no detailed discussions have taken place, but this is just due to the lack of information of costs and especially benefits. The topic is one of the most important ones, and is always present in the discussions and strategies. Pilots and trials with accompanying research actions are crucial to reduce the uncertainties. Data and sharing it seems to be beneficial in all cases.
- There may be unwanted effects like more traffic, less demand for public transport. Studies are often based on many assumptions on top of eachother.
- It is typical for all infrastructure investments by the public sector that they mainly bring benefits for other (private) stakeholders. The key target here is fairness so

that all stakeholders and citizens are treated equally. The budgets of the public stakeholders are limited, and investments will be directed to such actions with especially high benefits to the citizens and the industries. On the other hand, the public sectors are willing to provide support to socially beneficial services in their initial phases to get the service going, but quite reluctant to stay as a supporter for the long term.

- A business model need to be developed together with the industry. External actors are needed, and the road authority should support where we see societal benefits and not be a hinder.

Some concluded there is a lot that can be done with regard to quality of data e.g. more spending and fixing simple errors. A key account manager that could take an overall responsibility could be appointed.

Final workshop, online event September 30 2020

The final workshop was organised as an online event because of the COVID-19 situation. It was a one-day event consisting of a general introduction to the project and roadmap, in-depth interactive sessions on physical and digital infrastructure and costs & benefits, and a concluding session. In addition to consortium members, there were contributions from an OEM (Renault) and the European Commission (DG MOVE) on the agenda, and there were approximately 90 attendees online from various backgrounds.

The workshop highlighted some key factors in going forward: having all stakeholders working together, communication and exchange of views between the stakeholders, importance of end users, regulation to safeguard the wellbeing of travellers. Including users in the cooperation is quite challenging. Working together is needed to agree on infrastructure support levels and attributes, ODD investments, minimum risk manoeuvres, sharing of costs by those reaping the benefits, among other issues.

Digital twins were found as very useful, but evidently the concept is not understood in a similar way. However, there seems to be a commonly shared view of HD maps, digital traffic rules and regulations, etc.

There is a clear need for fair and equitable business models. Regarding those having the benefits should also be covering the costs – this is well established for some use cases and infrastructure (valet parking – parking establishments, remote fleet supervision – fleet managers and operators…) but unclear in many as well (dedicated lanes, facilitating accurate positioning,)

Update of the road map is important – something that we seem to often forget but luckily not always: ERTRAC is an excellent example of well updated road maps, providing an update every 2 years. This is likely the update interval for a dynamic domain like highly automated driving.

Something to take home from the workshop: We do not know enough, and we must learn faster and smarter!

A detailed report of the event can be found on the EU-EIP website, including results of the interactive sessions and the voting.