CEDR
Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

MANTRA

MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business

Road map for developing road operator core business utilising connectivity and automation

Deliverable D5.2 Version 0.99

28 August 2020

TRAFICON   ARNDT IDC   HiTec marketing   TUDelft   UNIVERSITY OF LEEDS   VTT

CEDR Call 2017: Automation

MANTRA

Project Nr. 867448

MANTRA

MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business

D5.2 Road map for developing road operator core business utilising connectivity and automation

Due date of deliverable: 31.07.2020

Actual submission date: xx.07.2020

Start date of project: 01.09.2018   End date of project: 31.08.2020

Author(s) this deliverable:

Risto Kulmala, Traficon Ltd, FI

Sandra Ulrich, ARNDT IDC, DE

Merja Penttinen, VTT, FI

Pirkko Rämä, VTT, FI

Walter Aigner, HiTec, AT

Oliver Carsten, ITS Leeds, UK

Marieke van der Tuin, TU Delft, NL

Haneen Farah, TU Delft, NL

Kristian Appel, Traficon Ltd, FI

Version: Draft 0.99

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Executive summary

Highly automated driving has been introduced and the roll-out of several use cases is expected to take place in Europe during the next five years. This deliverable is intended to support national road operators in the preparation to support the safe and effective introduction of those use cases. It provides input to road maps up to 2040 with regard to adaptations to be made to their core business and responsibility areas.

The following core business areas of the national road authorities were used in the analysis:

- Physical road infrastructure
- Digital infrastructure
- Operations and services
  - incident and event management
  - crisis management
  - traffic management and control
  - road maintenance
  - winter maintenance
  - traffic information services
  - enforcement
  - road user charging
- Planning, building, heavy maintenance
  - new roads planning and building
  - road works planning and management
  - heavy maintenance planning
- New business.

The work was carried out with focus on the five use cases in highly automated driving selected together with CEDR in MANTRA:
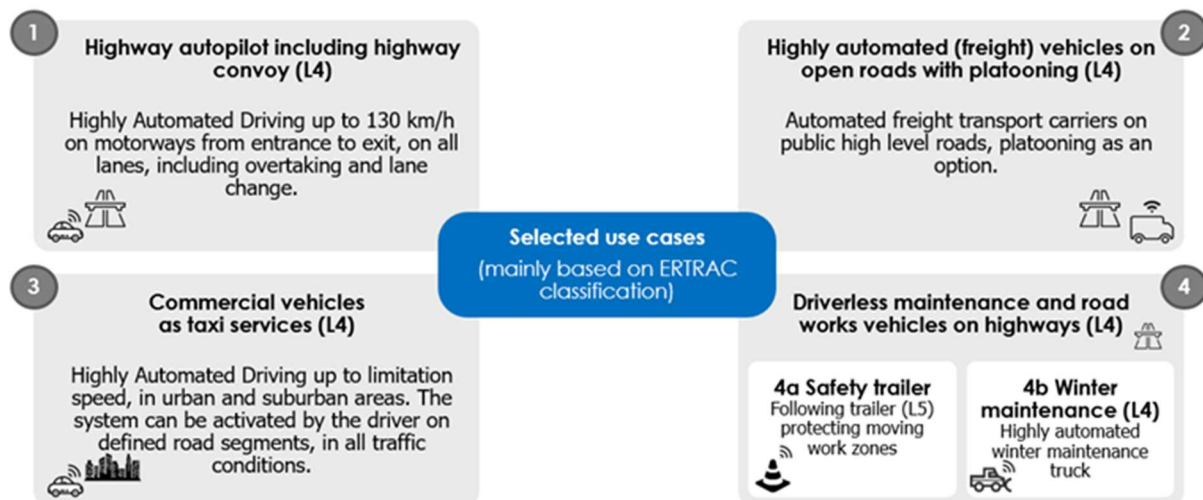
The impacts of highly automated driving on road authority core business will depend on many different factors related to the roll-out of automated vehicles. Some of the most important ones for the period 2020-2040 were identified:

- **when** will self-driving or driverless automated vehicles of SAE level 4 or 5 be on the market?

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

- what will the **market penetration** of self-driving or driverless automated vehicles of SAE level 4 or 5 be, and how will the mixed traffic composition look like?
- on **which part of the road network** can they operate as driverless/self-driving?
- in which **traffic and weather conditions** can they operate as driverless/self-driving?
- how and how much will their ability to operate as driverless/self-driving i.e. their **ODDs depend on the infrastructure assets**, their condition, and services of the road authorities?
- will highly automated driving cause a major change in the **socio-technical landscape** that will drastically modify the role and mission of the road authorities and operators?

MANTRA has provided some answers to the first questions already in early 2019. Since that, many of the roll-out forecasts for highly automated vehicles (for Europe) made before turned out to be too optimistic. It is likely that the ODDs for the highly automated vehicles (SAE Level 4) will be quite constrained, and the first use cases deployed will be automated shuttles and robot taxis, with a safety operator in the vehicle. The current surveys on acceptance of self-driving or driverless vehicles indicate reservations of many people towards such vehicles. Some experts think that fully automated vehicles will not be available until after 2070. Hence, it seems likely that the socio-technical landscape will not undergo a major upheaval due to the highly automated driving before 2040. However, SAE Level 1-4 automated vehicles will certainly be deployed during this period of time, affecting the road operators' core business.

To identify the changes in the socio-technical regime of e.g. organisations we have used the Multi-Level Perspective (MLP) theory. The core business of the NRAs can be understood as one socio-technical regime which is developing continuously but the structure of the regime is quite stable.

The analysis started with the investigation of the state of the art of the core businesses of road authorities in order to understand the related socio-technical regime. This investigation took also into account the changes due to digitalisation, electrification, urbanization, servitization and other megatrends in the socio-technical landscape starting with the current situation, followed by the Identification of drivers of socio-technical transition. These were societal, technical, design or other drivers of the socio-technical transition. Last, the challenges due to the roll-out of highly automated driving were elaborated upon.

On the basis of the findings of the other work carried out elsewhere in MANTRA, we then mapped the impacts of the selected use cases against the core business areas of the road operators i.e. the socio-technical regime via the impact of the functions on road operator policy goals as well as physical and digital infrastructure and their continuous safe and efficient operation. In this part of the report, the impacts of highly automated driving on the core business of the national road authorities were highlighted. The impacts were classified into four domains. The first one dealt with the impacts on objectives and mission, which reflect the "policy" dimension in the MLP model. The second one dealing with impacts on operations and use of technologies was related to the "technology" dimension, while the third one of impacts on NRA role reflected the dimensions of "culture", "markets", and "industry". The fourth one described the changes in the legal framework of NRA business.

The deliverable concluded with the road map development for changes in the socio-technical regime of the road authorities. The road map addresses the main core business implementation issues, and an indicative timing for national road authority and CEDR relevant implementation and other actions as well as a tentative recommended action plan for 2020-2024. This work was done by first preparing draft results which were then validated and elaborated on in a CEDR workshop in March 2020.

The road map in this deliverable consists of tables describing actions in different areas of the

national road authority core business areas up to 2040. The 92 actions of the roadmap tables were then prioritized via a web survey to NRA and other experts on automated driving which resulted in 22 priority actions. The actions were specified using a common template describing the business area, the content and timeframe of the action, the automated driving task and stakeholders affected, the legal prerequisites, the responsible stakeholders and their responsibilities, the roles of CEDR and NRAs, and the possible risks.

The emphasis of the priority actions is on studying and learning more about highly automated driving, its potential benefits and costs, restrictions, ODDs and requirements towards NRAs including the physical and digital infrastructure, traffic management, maintenance and other operations. An important result is that there are a number of no regret actions that can be carried out even without roll-out of highly automated vehicles. However, there are a few key actions linked to actual roll-out and deployment where immediate action is needed.

Table of contents

Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

List of Tables

List of Figures

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

1 Introduction

The CEDR Transnational Research Programme was launched by the Conference of European Directors of Roads. CEDR is the Road Directors' platform for cooperation and promotion of improvements to the road system and its infrastructure, as an integral part of a sustainable transport system in Europe. Its members represent their respective National Road Authorities or equivalents and provide support and advice on decisions concerning the road transport system that are taken at national or international level.

The participating NRAs in the CEDR Call 2017: Automation are Austria, Finland, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and the United Kingdom. As in previous collaborative research programmes, the participating members have established a Programme Executive Board (PEB) made up of experts in the topics to be covered. The research budget is jointly provided by the NRAs as listed above.

MANTRA is an acronym for "Making full use of Automation for National Transport and Road Authorities – NRA Core Business". MANTRA responds to the questions posed as CEDR Automation Call 2017 Topic A: How will automation change the core business of NRA's, by answering the following questions:

- What are the influences of automation on the core business in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes?

- How will the current core business on operations & services, planning & building and information and communication technology (ICT) change in the future?

An earlier CEDR project DRAGON (Vermaat et al. 2017) already looked at the impacts of three automated driving use cases in specific sites revealing the need to carry out a comprehensive study on the impacts on the road authorities and operators on the European scale.

MANTRA work started with the analysis of vehicle penetrations and Operational Design Domain (ODD) coverage of NRA-relevant automation functions up to 2040. This part is reported in MANTRA Deliverable D2.1 (Aigner et al. 2020). Following, this work-package 3 concentrated on the impacts of connected and automated driving (CAD) and how the impacts related to the role and policy targets of NRAs. The impacts of CAD on travel demand, travel behaviour, traffic flow, safety and energy have been reported in D3.1 for literature and D3.2 for MANTRA 's own results (van der Tuin et al. 2020). The work-package 4 focused on the consequences of automated driving to physical and digital infrastructure, and the results are documented in deliverable D4.2 (Ulrich et al. 2020).

This deliverable compiles the results of MANTRA concerning the impacts on highly automated driving on the core business of road authorities and operators.

1.1 Objectives

The objective was to identify the main changes in road authority and operator core business due to connectivity and automation, and specifically due to highly automated driving within the time frame of 2020-2040. This was to be carried out in light of the five specific use cases for highly automated driving selected for MANTRA:

- Highway autopilot including highway convoy

- Highly automated freight vehicles on open roads with platooning

- Commercial vehicles as taxi services (robot taxi)

- Driverless maintenance and road works vehicles on highways - safety trailer
- Driverless maintenance and road works vehicles on highways - winter maintenance vehicles

The core business areas were already determined in the CEDR research call as those shown in Figure 1.
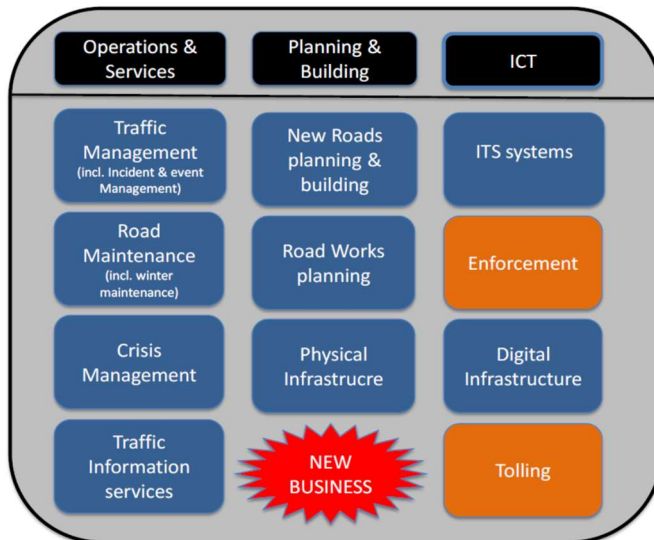
Figure 1 Road authority business areas (CEDR 2017).

1.2 Approach and methodological framework

The impacts of highly automated driving on road authority core business will depend on many different factors related to the roll-out of automated vehicles. Some of the most important ones are for the period 2020-2040:

- when will self-driving or driverless automated vehicles of SAE level 4 or 5 be on the market?
- how large part of the road network can they operate as driverless/self-driving?
- in which traffic and weather conditions can they operate as driverless/self-driving?
- how and how much will their ability to operate as driverless/self-driving i.e. their ODDs depend on the assets and services of the road authorities?
- will highly automated driving cause a major change in the socio-technical landscape that drastically modify the role and mission of the road authorities and operators?

MANTRA provided some answers to the first questions in D2.1 (Aigner at al, 2019). During 2019, many of the forecasts of roll-out of highly automated vehicles made before (such as those listed by Chen, 2017) turned out to be too optimistic. It is likely that the ODDs for the highly automated vehicles (SAE Level 4) will be quite constrained, and the first use cases deployed will be automated shuttles and robot taxis, with a safety operator in the vehicle.

The current surveys (e.g. AlixParters 2020) on acceptance of self-driving or driverless vehicles indicate reservations of many people towards such vehicles. Experts like Steve Shladover (2019) think that fully automated vehicles will not be available until after 2070. Hence, it seems likely that the socio-technical landscape will not undergo a major upheaval due to the highly

automated driving before 2040.

The Multi-Level Perspective (MLP) theory conceptualizes overall dynamic patterns in socio-technical transitions. The theory views transitions as non-linear processes that result from the interplay of developments as illustrated in Figure 2. The core business of the NRAs can be understood as one socio-technical regime which is developing continuously but the structure of the regime is quite stable.
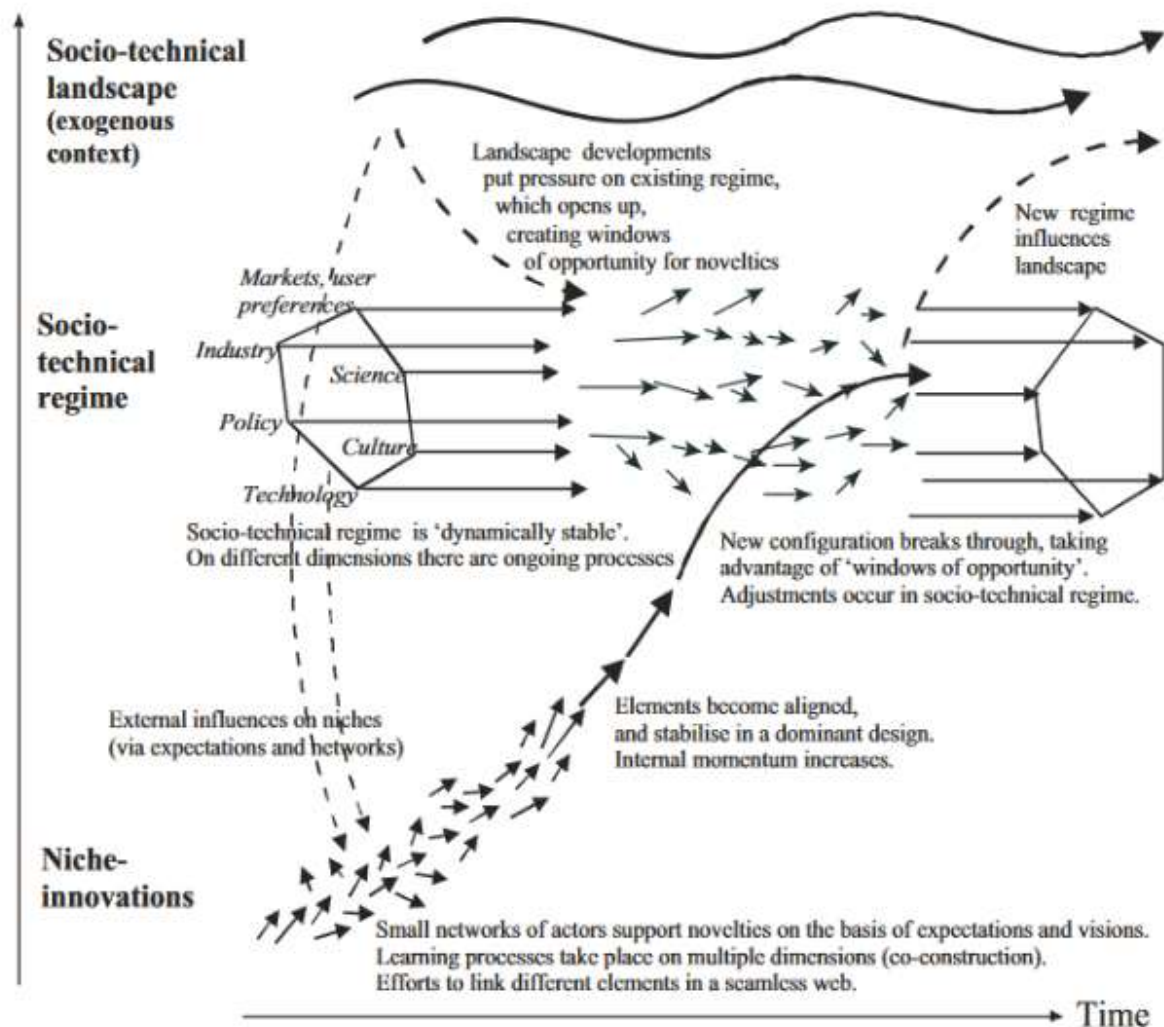
Figure 2 Multi-level perspective on transitions (Geels 2011).

Highly automated driving and automation in general can be viewed as a development of the socio-technical landscape opening up new opportunities for enhancing the core business and adding new services. This is supported by findings in the industry. McKinsey (2020) notes that prioritising business-process automation is increasingly important to success, and rethinking operating models, including how different functions work together, has emerged as a new imperative. At the same time, some of the highly automated driving use cases and their evolutions can be regarded as niche innovations, which may also be aligned and strengthened to result in changes in the socio-technical regime. Changes in the regime in turn influence the

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

landscape.

The application of the multi-level perspective on NRA core business is illustrated in Figure 3.
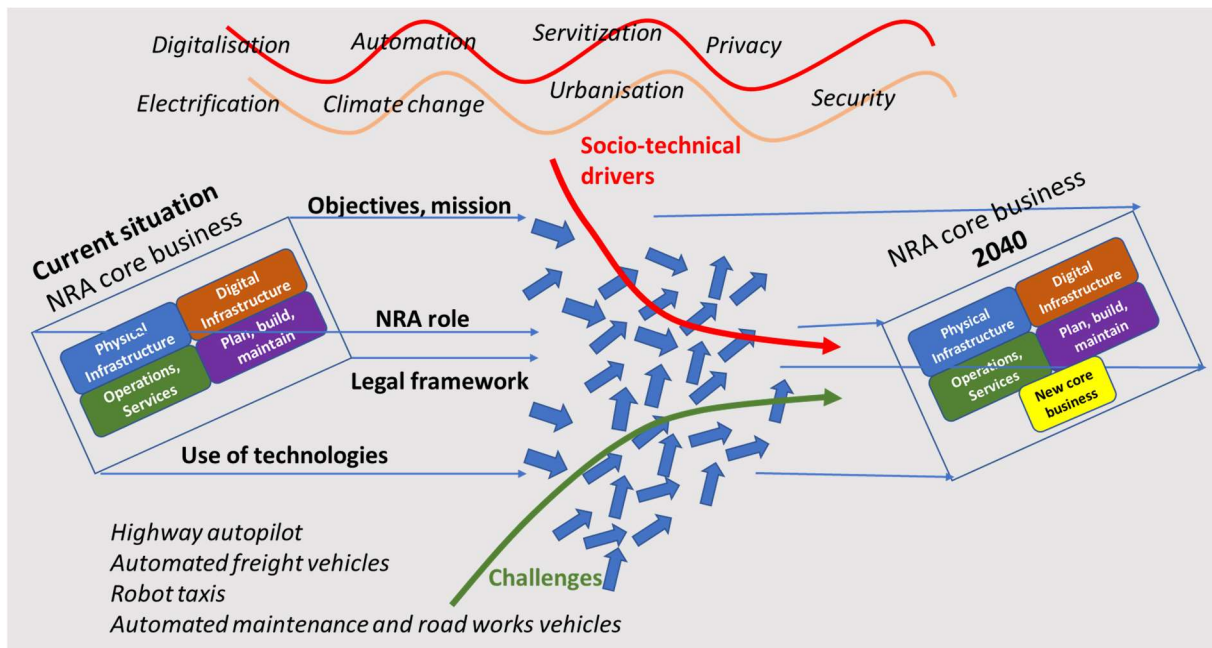
Figure 3. The application of the multi-level perspective in NRA core business evolution.

The work described in this deliverable started with the analysis of the state of the art of the core businesses of road authorities in order to understand the related socio-technical regime. This analysis took also into account the changes due to digitalisation, electrification, urbanization, servitization and other megatrends in the socio-technical landscape.

On the basis of the finding of the WPs 3 and 4, we then mapped the impacts of the selected use cases against the core business areas of the road operators i.e. the socio-technical regime via the impact of the functions on road operator policy goals as well as physical and digital infrastructure and their continuous safe and efficient operation. Specific attention was given to the impacts on objectives, mission, operations, use of technologies, role and the legal framework of the national road authorities.

An important part of the work was the road map development for changes in the socio-technical regime of the road authorities. The road map related to addressing the main core business implementation issues, giving an indicative timing for national road authority and CEDR relevant implementation and other actions, and a tentative action plan for 2020-2024. The work was done by first preparing the draft results and then elaborating on and validating them in a CEDR workshop in March 2020.

CEDR Call 2017: Automation

MANTRA
2 Core business of the road operators – state of art

For each core business area, the state of the art analysis starts with the current situation, followed by the Identification of drivers of socio-technical transition. These drivers can be societal, technical, design or other drivers of the socio-technical transition. Last, the challenges due to the roll-out of highly automated driving are elaborated upon.

2.1 Physical Road infrastructure in Europe

Current situation

Dependent on its importance, demand and location, physical road infrastructure has to fulfil manifold sets of requirements. There is no such thing as one single standard for road infrastructure throughout Europe that could be easily amended to prepare for automated and connected vehicles. Instead, the various road categories, their specific design requirements, traffic loads and complexities have to be assessed individually and from different angels.

Road infrastructure in Europe is heterogeneous for diverse reasons. Geographic and climate conditions vary greatly from North to South but also traffic density, volume and transport problems within each of the countries differ depend on location and road category. CEDR members have varying responsibilities for either solely high-level road networks (motorways and highways) or different types of roads from motorways to urban roads and everything in between.

CEDR members are also responsible for major parts of the strategically highly important TEN-T network and document the performance of the TEN-T road network within CEDR participating countries in regular reports. The Trans-European Transport Network (TEN-T) is a European Commission policy directed towards the implementation and development of a Europe-wide network of roads, railways, inland waterways, maritime shipping routes, ports, airports, and rail-road terminals. The TEN-T Roads network in the participating CEDR countries is approx. 84,700 kilometres long. Approx. 42% of these roads are Core Roads and 58% are Non-Core Roads and the network comprises approx. 61% of motorways and 39% of non-motorway roads. (Pettersson et al. 2018)

Traffic flows vary considerably from country to country: Belgium (Flanders), the Netherlands, and the United Kingdom (England) have the TEN-T roads with the highest traffic volumes, with more than 20% of their network carrying more than 80,000 vehicles per day. On average, 13.7% of the traffic using the TEN-T network is made up of heavy goods vehicles, with this share remaining consistent for both motorways and non-motorways (Pettersson et al. 2018).

The physical infrastructure consists of different elements that are generally grouped into 4 main asset groups being:

- Road/pavement
- Bridges/structures
- Tunnels
- Road equipment

Each of those assets has developed over time to cater for the needs of road users and the policy goals of NRAs. Those needs and policy goals continue to evolve with automated vehicles but still have the same intention to provide safe roads for the according traffic volume. Ongoing developments look at the evolving ODD requirements for different highly automated vehicle use cases and what adaptions are needed to enable their implementation.

Identification of drivers of socio-technical transition

The developments of physical infrastructure are driven by the policy goals of NRAs usually being road safety, traffic efficiency, environmental improvements and customer service. As physical road infrastructure is costly and long lasting the need for economically sensible adaptions is paramount.

The impacts of automated driving are due to the actions to be carried out to provide the ODDs for use cases to be deployed on one hand and the expected effects of the use of automated vehicles on the physical infrastructure on the other hand (Ulrich et al, 2020). ODDs are driven by societal, technical and design factors alike.

The current main societal drivers for physical infrastructure definitions include:

- travel behaviour developments with road users may change their travel behaviour due to automated transport options resulting in heavier or lighter traffic volumes which impact deterioration of pavements and structures as well as design guidelines

- road safety improvements towards the vision zero aim of reducing road deaths to almost zero by 2050 (Trafikverket 2015) and enhancements of the physical infrastructure to provide or enlarge ODDs even if they are costly driven by the promising potential of automated vehicles for road safety improvement

- environmental considerations driven by global discussions and the European Commission ambitions formulated in the European Green Deal towards significant emission reductions (EC 2019)

Technical drivers for physical infrastructure developments as well as design factors along automation are and will be defined through the ODD definitions of automation use cases to be implemented. In a similar fashion, several automated driving use cases and their ODDs likely need to adapt to road operator views for instance to avoid thousands of minimum risk manoeuvres at the same time at the same location.

Several forms of predictive maintenance will likely drive rapid integration of automated vehicles due to their anticipated high compliance towards requested or recommended behaviour, e.g. to distribute rather equally on bridges, or in sensitive physical infrastructures.

Challenges

Physical infrastructure adaptations are very costly, need to be planned far ahead and are also heavily regulated in each country with technical standards. Developments in automation are fast paced and often subject to bold announcements, which makes it difficult also for NRAs to distinguish between developments for which physical infrastructure provisions need to be taken as soon as possible on the one hand and pure hype on the other. This contradiction is the main challenge for physical infrastructure developments.

It would be beneficial to have a clear picture of likely concrete consequences and necessary proactive adaptations due to selected automated functions' ODD requirements or infrastructure impacts. The tricky aspect for decisions is the constant evolution of the ODDs. This evolution 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 NRAs is however to analyse their networks and prioritize where deployment of connected and automated driving use cases is most suitable and sensible.

In terms of impact due to the use of automated vehicles, road operators are partly able to

influence whether or not specific automated driving use cases (such as e.g. truck platooning or highway autopilot) are going to be allowed on their networks and which adaptations are necessary. Amendments therefore need to be well thought through. Most required infrastructure support will be on the digital part, and physical infrastructure amendments should be very carefully selected. It will be necessary for automated vehicles to limit the dependence on physical infrastructure because of the cost (Vreeswijk 2019).

2.2 Digital road infrastructure and ITS systems in Europe

Current situation

The deployment of digital road infrastructure is taking place to meet NRAs' mission and objectives. These include, for instance, the need to mitigate risks at traffic hotspots and incident hotspots and to improve coping mechanisms towards high impact incident, events and crises. The aim is to provide a future-proof road infrastructure – including digitalisation – in a rather heterogeneous landscape in Europe both throughout a transition period as well as in times of fully operational and widely penetrated highly automated vehicle functions.

Digital infrastructures are today seen as sustainable with effective digital ecosystems. This rather diverse or yet emerging concept of roles in building an effective ecosystem for operation in a digital Europe has significant elements for adaptation within the roles of the NRAs.

Different dynamics are in place concerning the NRAs' current situation and key NRA challenges in different regions and cultures in Europe. Specifically, the role of digitalisation on strengthening a country's or region's economic competitiveness in a global innovation system is more easily recognised in some cultures. Some NRAs do not explicitly mention fostering a country's economic competitive capacity in their objectives – beyond maintaining core functionalities of an efficient and safe road operation. This might change in the future.

Identification of drivers of socio-technical transition

Digital infrastructures are increasingly seen in need of effective digital ecosystems and cooperation platforms. As a consequence, when selecting their partners in the ecosystems, the NRAs are considering aspects such artificial intelligence, cyber security, complexity science, resilience, etc.

Digital capabilities have become an explicit element in European policies. The European data strategy lists as one of five illustrating examples "real-time traffic avoidance navigation can save up to 730 million hours. This represent up to Euro 20 billion in labour costs." In total, the value of the data economy is expected to increase to Euro 829 billion or 85.8 per cent of EU GDP. (EC 2020) The NRAs are anticipated to face requests into how they are proactively contributing to a sustainable and effective European data ecosystem.

The vehicle manufacturers will always try to maintain their services also in cases without any availability of or cooperation with networks nor non-vehicle manufacturers' proprietary traffic control centres. On the other hand, the vehicle manufacturers also state that "before automated vehicles can become a common sight on our roads … Europe needs to upgrade, adapt and harmonise physical and digital road infrastructure to make it suitable for automated driving" (ACEA 2019).

The concepts of adequate traffic management might change in yet unanticipated ways. In the times of cyclists, pedestrians, greening Europe and demographic changes, the digital infrastructure can possibly evolve to involve entirely new bottlenecks and management needs such as more space, safe operation, car free zones, new vehicle-like elements, etc. especially in urban areas.

The increasing traffic volumes, with different forecasts for freight and passenger traffic in different areas in Europe, are seen as one driver for future digital infrastructure evolution. Another driver is the increasing number of severe weather situations and large events. Additional ones are the increasing level of assisted driving at least with premium cars and premium service providers, and the increasing level of AIs becoming available – with further boosts into digital infrastructure including sensors etc. The changes due to COVID-19 indicate that also pandemics and similar global phenomena might also act as relevant transition drivers.

At the same time, we have increased awareness of cyber security issues – even stronger in a world of rather strong cooperation between ecosystem stakeholders outside the traditional NRAs sphere. NRAs are responsible for providing and maintain of physical and digital infrastructure thus proper approach of managing cybersecurity risks should be a top priority (Strand, et al. 2020). We also have an increasing dependency on continuity and seamless hand-over in a diverse digital ecosystem.

An increasing number of stakeholders, commercial players, and traffic or fleet control centres outside the traditional NRA community are entering the road transport domain. This development involves issues such as how effective safety critical cooperation and "roaming" is organized, and who takes the coordination role in a world of multiple traffic control centres. Concerning the latter, there are major differences between European countries concerning the role of the public sector in traffic management and control.

The digital infrastructure is also used for a wide variety of infotainment services. 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. These services may have high requirements for large-bandwidth low-latency communications.

The different innovation speeds for chip manufacturers, mobile network operators, road operators, and other digital service providers need to be taken into account in the deployment and operation of digital infrastructures.

The risk mitigation and the availability of several digital networks are anticipated to lead to competitive "invitations" from external stakeholders to NRAs into bundling and pooling of digital road infrastructure to reduce deployment cost and or to achieve critical data rates in early car connectivity penetration stages. It is evident that no full infrastructure will normally be deployed for sections where only a few cars will need the specific digital infrastructure.

Challenges

Digitalisation is – in one way or the other – based upon promises from having a digital representation of what happens in real world and the promise that automated decision making or automated preparation of decision making have the potential to fuel entirely new mechanisms for NRAs. However there have been significant concerns that in an exceedingly complex world of sensors and automated interactions the technologies for effectively coping with this complexity have yet to be invented and it remains to be seen whether and how these new technologies can be effectively absorbed by NRAs (concept of absorptive capacity). A realistic picture would show that most road operators currently prefer to deploy information technologies that have been around for some twenty years. This has partly been related to safety critical infrastructures, but also to the rather limited roles of innovation in every day purchasing routines.

Selected flagship initiatives in digitalisation and innovation should not be mistaken as sufficient for making a digital stakeholder a skilled process operator or competent cooperation partner in a world of rather dynamic digitally enhanced mobility value chains.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

The statement "digitalisation of infrastructure never ends" has been seen repeatedly in the context of European Telecom representatives when they have been discussing European physical infrastructures like highways, railways, airports, ports, and logistic hubs. This is a challenge that will most probably always see new frontiers. In the context of European infrastructure operators who are currently using / rolling out digitalisation technologies as of the year 2000 – the statement illustrates also an increasing challenge for NRAs.

The polarization between fully digitally equipped urban/peri-urban areas and rural areas will be less accepted in the society. To improve road safety and efficiency at already highly safe highways and urban roads has lost part of its society-wide appeal. The differences in quality of life and the competitive strengths in economies have played one part in this public perception. Within the high ranks of road operator interest groups the issue of having relevant contributions to all voters and not just those using high-end vehicles have been prominently raised e.g. during EUCAD conferences in Brussels 2017 and 2019.

An effective preparation of competitive regions in a global ecosystem is increasingly seen as an accompanying activity for future economic strength, attractive work environments and quality of living. This has significant potential to require NRAs and more generally almost any stakeholder in future distributed value networks to make effective network capacity available without waiting for adequate diffusion of related technologies in vehicles, modems or mobile phones. The request to deploy almost network-wide and prior to significant penetration of user devices increases technological, commercial, and financial risks from investing early. Such risks are increased due to the absence of any guarantee that significant market take-up will happen before a new communication technology might become available forming yet another new investment requirement. With ever shorter innovation cycles this provides significant challenge to NRAs.

Data sharing has already been identified as a challenge with connected vehicles, and this is expected to apply also to highly automated vehicles. This applies not only to the data itself, but also use of harmonised common data protocols, data interchanges, cybersecurity solutions, user privacy and rights to use data.

There is a need to align the different deployment strategies among OEMs, NRAs, mobile network operators, and service providers at least to a sufficient extent to enable safe, efficient and clean mobility involving also highly automated vehicles.

Geographical, jurisdictional and organisational borders are an issue also in digital road infrastructure. MoUs and cooperation agreements may be difficult to make due to differences in national, regional and local regulations. In addition to NRAs, a rather high number of local road operators including cities will be a challenge.

Traditionally, the interoperability of services and infrastructures from the European NRA perspective "has clear and strong procedures". "However, the existing NRA concepts of interoperability might need some complementary mechanisms like interworking and coexistence." (several verbatim statements from DG Connect reflecting on current cooperation practices during a workshop on preparing upcoming digital infrastructure programmes for 2021: workshop "CAM challenges towards cross-border deployment, 13 February, 2020 Brussels")

The increasing convenience in highly automated cars might increase traffic volumes considerably, which would be a major challenge for all road operators, including NRAs.

The heterogeneity of the automated driving systems from different Automated driving system providers and OEMs even for the same use case will result in many issues. First, the ODDs may differ widely. Second, vehicle behaviours may be so different that developing a suitable traffic management process for all vehicles will become extremely complex. Third, the users will likely want to switch off the automated driving mode at their will, and how will the road

operator be aware of this? Fourth, the quality and type of real-time information required may vary considerably, and which should the road operator choose. Fifth, the competition between different mobility service providers and e.g. car manufacturers' premium services might introduce systemic deviations from the perspective of almost equally distributed "uninformed" drivers today. This has the potential to either outcompete road operators' information services by premium service providers or road operators in a role as innovative mobility service partners in a distributed mobility value chain might treat different user groups with different service levels or even different priorities.

The issues with minimum risk manoeuvres need to be solved also in situations involving connectivity and digital infrastructure. For instance, how to solve a situation where a group of "linked" cars reduce its speed on a left lane on a continental motorway to less than the usual speed on this lane in cases where a collaborative manoeuvre needs to be terminated? Other examples include huge numbers of vehicles commencing minimum risk manoeuvre at the same time approaching work zone or on a bridge or other sensitive physical infrastructure element or experiencing heavy rain or snowing.

The commercial automated driving services may need high quality digital infrastructure especially in areas where passengers would hop on or off the vehicles, and these could be also in areas, where historically digital infrastructure was not needed. This calls for investments unless other solutions could be developed in cooperation with the stakeholders involved.

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.

There is a rising trade-off between cost of deploying digital infrastructure early even with only a few users, and having new technologies or devices become available quickly reducing the break-even window for private operators. Hence, it is likely that different stakeholders are willing to utilise the NRAs' fibre optics infrastructure.

Convincing integration of diverse high quality real-time information to one situational picture will provide a significant driver as well as a challenge. The key automation concepts of ODD, ISAD and information provision tools (HD Map) are to be integrated under the umbrella concept of the digital twin for the road transport system with rapid prototypes demonstrating the viability.

Digital maps are a key element in the digital infrastructure, and digital map providers make it possible for NRAs and other road operators to provide HD maps on their infrastructure as a service. Relying on such a service carries a risk of higher costs if there is not a sufficiently competitive market and also a more fundamental risk for operations as the HD map of road infrastructure is a strategic asset for a road operator. Another challenge is linked to the fact that HD maps may be inaccurate and inconsistent due to various reasons. It is also possible that road operators have the potential to support automation by creating their own HD maps. This could be driven, for instance, by the need to have highly automated road building, road works, and maintenance vehicles.

2.3 Operations and services

2.3.1   Incident & event management

Current situation

Traffic incident management is a structured response to road traffic incidents. The remit of incident management is to develop joint working practices between national road administrations, the police, and other incident responders to ensure the mutual achievement of objectives including the safety of both road users and responders, reduced congestion and economic costs, and improved travel reliability and efficiency. It can in practice be defined by a sequence of phases from the discovery of the incident to its clearance and the restoration of normality. Incident prevention is a natural companion of incident management. Just as incidents arise from combinations of factors, so successful incident prevention may depend on a combination of measures: analysis and intelligence, driver information and education, and physical measures. (CEDR 2011)

Incidents are critical to the road authorities and operators as they are a major source of congestion – in the USA, 25% of congestion on freeways is due to incidents (FHWA 2010). A range of 10-25% has been estimated for Europe (CEDR 2011), but on rural roads with low traffic volumes even two thirds of congestion can be caused by incidents. The incidents can also result in so-called secondary accidents. According to FHWA, the likelihood of a secondary crash increases by 2.8 percent for every minute that the primary incident remains a hazard.

Due to the importance of traffic incidents, road authorities have prepared guidelines for incident management (e.g. CEDR 2011, FHWA 2010, Highways Agency 2009). These give strategic, tactical and operational guidance on dealing with the issues of incident management operations and their planning. These guidelines do not yet take into account connected and automated vehicles.

Events consist of sports, cultural or other events with high participant numbers. They can be stationary events, in which case exceptionally high traffic volumes will disturb the road users especially at the starting and closing times of the event. They can also be moving events, for instance walking or running competitions, cycling tournaments, parades, or convoys of slow vehicles.

Events are similar to incidents in that they also cause disturbances and congestion in the road network. For that reason, traffic management plans are being developed and maintained for both incidents and events. Such plans will provide traffic managers and other stakeholder involved with well thought out plans for the different actions to be carried out when managing the incidents or events.

They are, however, predictable and their location, duration and possible influences are often known for several days before the event. Hence, the road operator can prepare for them in advance, and thereby the influence of the event can be mitigated. Guidelines for special event traffic management exist (e.g. Queensland 2018, FHWA 2011)

It is noteworthy that the number of stakeholders is quite diverse, affecting also the management of events. The following responsible stakeholders/persons have a role in special event traffic management: Event organiser, event traffic marshal, parking assistant, police officer, support vehicle driver (to perform event-related duties such as accompanying event participants or providing a 'sweep' function at the rear end of a mobile event), traffic controller, and traffic management design competent person. (Queensland 2018)

Identification of drivers of socio-technical transition

Societal drivers

The importance of incident and event management has increased as they have had an increasing role as disturbances in the reliability of transport, and especially goods transport. In goods transport, the predictability of supply chain and related delivery times are essential to logistics and industrial processes.

For private motorway operators, efficient incident and event management is very important to keep their customers satisfied, and also to attract new users.

Technical drivers

In the domain of incident and event management, stakeholder cooperation is essential. While the cooperation relies on well-functioning communications between the different stakeholders, the evolution of communication technologies is a key technical driver in the development of incident and event management. At the same time, automation has been seen as a way to make the related processes safer and more efficient.

CEDR (2011) provided a list of ten points making up the backbone of traffic incident management (Figure 4). It is likely that the points 1, 2, 5 and 10 would be enhanced with the involvement of connected vehicles, and that points 4 and 7 could benefit from such vehicles. Already new vehicles type-approved since 2018 are equipped with automated emergency call system eCall (European Parliament 2015), which will certainly benefit points 1 and 2. Highly automated vehicles would likely improve points 1, 2 and 10 with the help of their advanced sensors and AI, and point 4 with automated safety trailers and maintenance vehicles.

These ten points make up the backbone of incident management:

1. Speedy detection and response
2. Good information about location, severity, and any attendant hazards
3. Protection of the scene and ensuring the safety of responders, victims, and the public
4. Coordinated response with a clear structure of authority, roles, and responsibility
5. Reliable communications between responders and with the public
6. Provision of appropriate equipment, facilities, access paths, and control centres
7. Sufficient backup services to ensure speedy clearance to minimise congestion
8. Training and debriefing systems
9. Written guidelines and formal agreements, where necessary
10. Monitoring, performance assessment, and feedback into practice.

Figure 4. Backbone of incident management (CEDR 2011).

The concept of proactive incident management and incident prevention is currently being developed and implemented, with a role seen for connected vehicles. Figure 5 shows a concept proposed by the CEDR project PRIMA (Weekley et al. 2017).
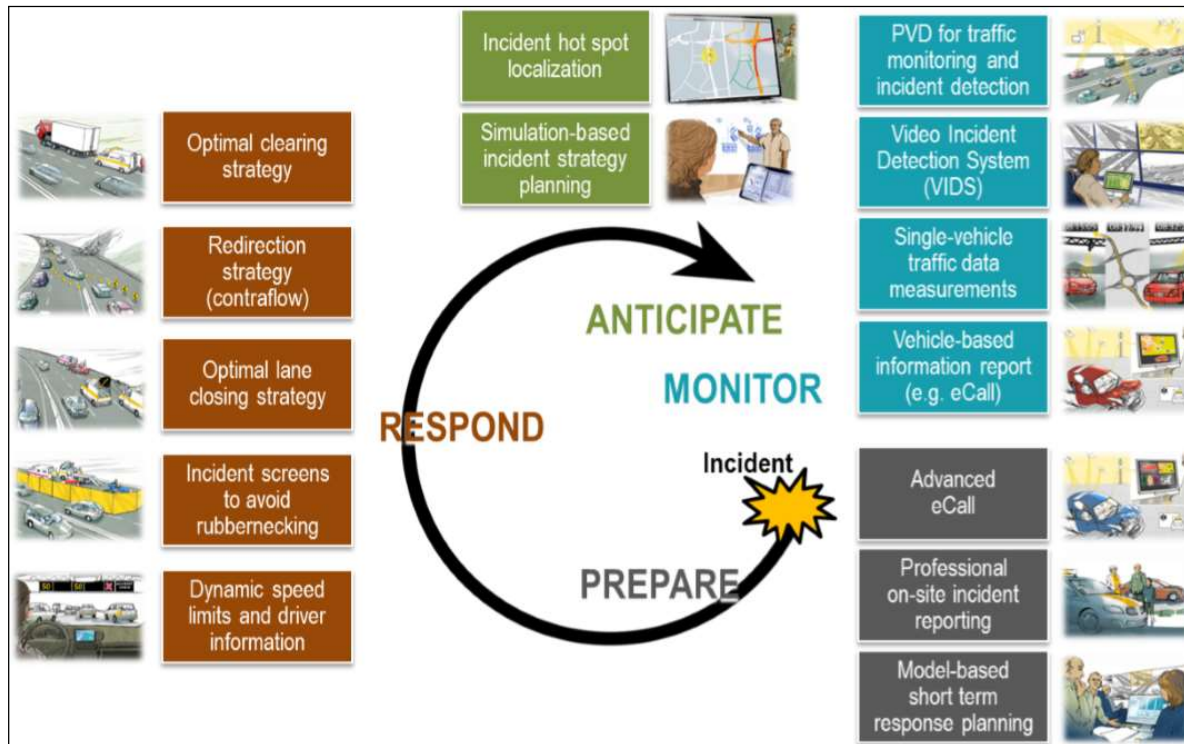
Figure 5. Recommended pro-active incident management techniques in PRIMA (Weekley at al, 2017).

Challenges

Connected vehicles have an important role especially in incident detection, but also in the other phases. So far, the role of automated vehicles has not been covered.

Currently, the practices in incident management have been primarily 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. With connected and automated vehicles, vehicle manufacturers, C-ITS service operators and automated vehicle fleet managers enter the picture, and will have a role to play also in traffic incident management.

Harmonisation of traffic rules and operational procedures has been suggested by the vehicle manufacturers (ACEA 2020). However, the existing differences in operational procedures among NRAs are most often the result of experiences with handling real incidents. Thereby there is a risk that harmonisation could hide or override underlying operational knowledge for the sake of cheaper service provider costs with transnational service providers.

In traffic management of events, 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.

2.3.2   Crisis management

Current situation

Traffic incidents and events occur all frequently all over the road network. Events that are more serious in nature are commonly referred to as crisis or emergency events. Crisis or emergency management brings together different stakeholders to respond to, and manage, these events.

Emergency events include events of which there is little or no advance notice – and known events for which the impacts are largely unpredictable – such as a hurricane/typhoon/cyclone. (PIARC 2020)

The scope or severity of incidents is a continuum along which the responders and managers change and the team expands according to the severity of the event. The diagram in Figure 6 illustrates this continuum. Whatever the severity, first-line responders generally include law enforcement, fire rescue, emergency medical services, vehicle breakdown and recovery teams – and in the transport community, the road authority's maintenance teams and mobile safety service patrols. The traffic management centre will be involved throughout as well. The involvement of agencies providing oversight and support will change as the severity increases – to include other stakeholders such as emergency managers, local, regional and national agencies. (PIARC 2020)

The usual practice is to designate an emergency coordination centre from amongst the first-line responders. Often the traffic management centre is well-placed to take this role. Where possible, the demarcation and allocation of responsibility for public statements, policies on the use of social media and press briefing – for different kinds of emergency, needs to be worked out in advance between those with a close interest. (PIARC 2020)

Identification of drivers of socio-technical transition

Societal drivers

The society has on one hand become more vulnerable to crisis and emergency events due to the minimisation of storages due to reliance on efficient logistical processes, and on the other hand more efficient in handling these events due to more efficient cooperation and communication processes. Due to the increased vulnerability, there is a constant need to improve and maintain efficient crisis management capabilities.
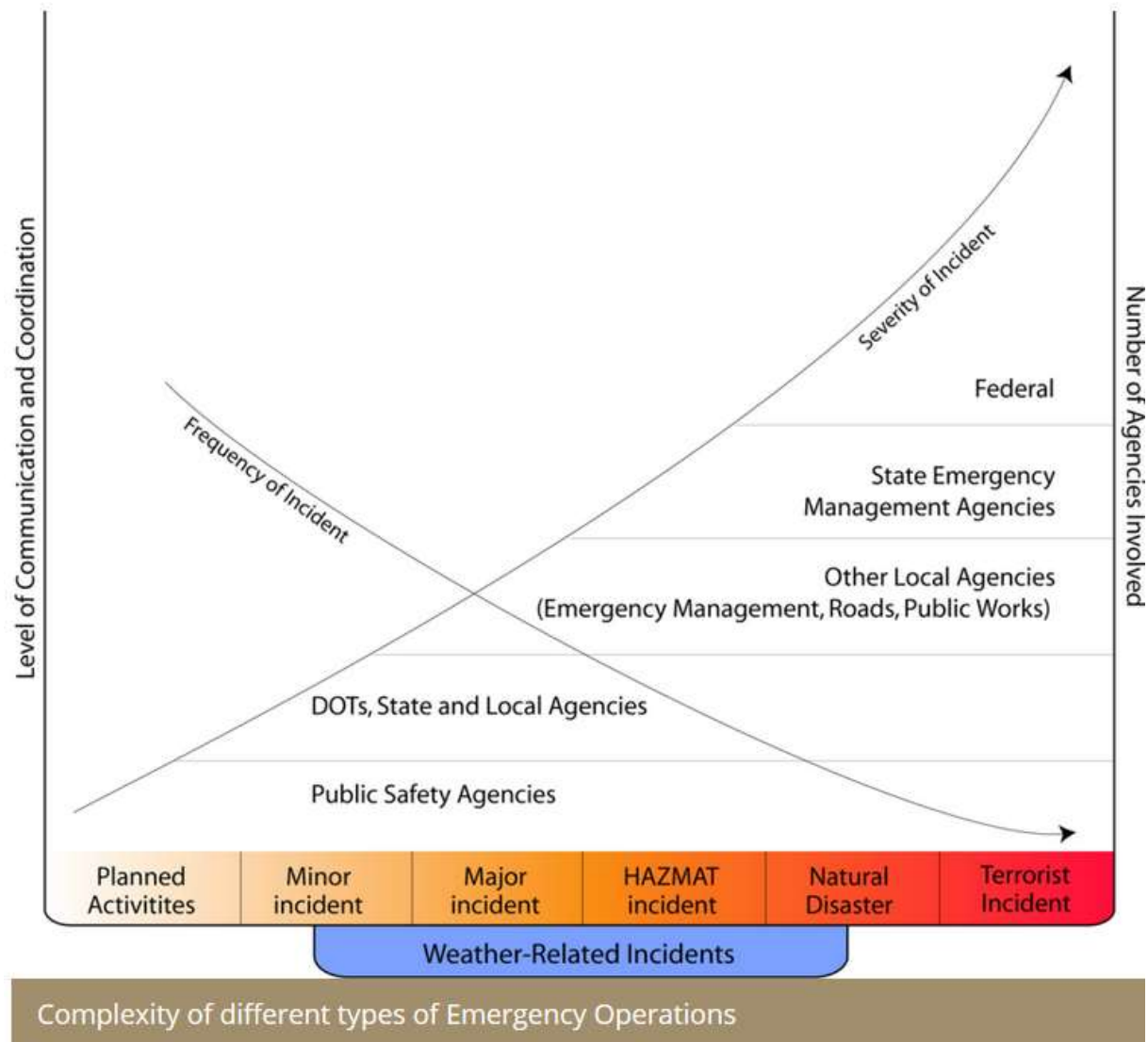
Figure 6. Continuum of incidents and emergencies (PIARC 2020)

Technical drivers

As with incident management, stakeholder cooperation is essential and thereby, the evolution of communication technologies is a key technical driver in the development of crisis management. Systems already in the market such as eCall will improve crisis management. At the same time, automation has been seen as a way to make the related processes safer and more efficient.

The improvement in the crisis management processes and procedures due to connected and automated driving are similar to those listed earlier for incident and event management.

Challenges

The role of highly automated vehicles in crisis management has not been seriously addressed so far. Driverless and self-driving vehicles could have a major role in evacuation and rescue operations. However, there is also a possibility that in some crisis situations the crisis itself is of the nature that the automated vehicles do not have the ODD to continue driving – for instance through walls of flames or on flooded roads.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

The crisis may in some cases be related to the essential infrastructure for the highly automated vehicles. For example, the communication networks might not function at all due to a terrorist attack or a nature catastrophe.

An important challenge is the possibility of the self-driving or driverless vehicle used to create a crisis such as a terrorist act. Some safeguards need to be put in place to prevent this.

2.3.3 Traffic management and control

Current situation

Today, traffic management typically contains the services of signal control, access control, dynamic lane management, variable speed limits, ramp control or metering, hard shoulder running, incident warning and management, heavy goods vehicles overtaking ban, traffic management plan. Traffic management is often defined as also containing traffic information, but that is in this document dealt with separately. Traffic management/control has been carried out for decades, and it has been also harmonised and standardised. The most recent harmonisation action in Europe is the reference handbook for harmonised ITS core service deployment (EU EIP 2020).

Traffic management services and systems are deployed at specific spots (junctions, tunnels, bridges), on road sections, and on corridors and networks. The services are operated by local, regional or national traffic management centres. The basic mission of traffic management and control is to ensure road safety and efficiency as well as minimise congestion and environmental impacts by providing the road users information, advice and guidance via fixed and dynamic traffic signs and road markings.

The operation of traffic management services is based on data acquired by different monitoring systems. Traditionally these monitoring systems have been based on fixed monitoring stations utilising inductive loops, radars, weather sensors, cameras, and other sensors. Naturally the data relates only to the spots where the monitoring station is located. Having better and more data throughout the network via vehicles as mobile sensors has been studied and also deployed already for almost 20 years. The pros and cons of FCD (Floating Car Data), mobile phone data, and FVD (Floating Vehicle Data) have been documented widely. The main conclusion seems to be that the penetration rate of "floating vehicles" for single service providers is too low to provide reliable data throughout the day or to detect incidents quickly enough for traffic managers – already highlighted more than 10 years ago by e.g. Brockfeld et al. (2007).

Identification of drivers of socio-technical transition

Societal drivers

The key objectives of ensuring road network safety and throughput will be accompanied with the objective of minimising carbon and particulate emissions from traffic as well as their consequences. This will likely result in the development and upgrading of traffic management tools, and make e.g. demand management and access control more widely used than today.

New stakeholders have entered in the field of traffic management. Navigation service providers did so more than 20 years ago, and fleet managers are entering the business along with their connected fleets. This calls for new traffic management related governance and cooperation processes.

MANTRA

Technical drivers

Connected and automated vehicles might alleviate the problems of lacking and poor quality mobile sensor data with reasonable penetrations by 2030, at least if the data on traffic and environmental conditions is shared between the different vehicle and automated driving system manufacturers. Unfortunately, there is no certainty that such sharing will take place. The sensors of connected and automated vehicles will provide a lot of data of the traffic and environmental conditions along their route. Such data would be extremely useful to the road operators and traffic managers. At the same time, the availability of such data would enable road operators to give up large parts of their monitoring infrastructure resulting possibly in cost savings. On the other hand, the vehicle and information service industry is not willing to give for free the data that they have collected via connected and/or automated vehicles. The only type of data, which also the industry needs to share according to European legislation is safety-related information. This information, detailed in eight information types, has to be shared on the basis of the delegated regulation for road safety-related minimum universal traffic information free of charge to users (EC 2013). This has been the basis of 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)

With regard to the operation of traffic management systems, automation will have a major impact on the systems themselves. Many of the tasks of human operators in traffic management centres and be taken over or supported by automated or autonomous functions. The traffic management systems and centres are implementing the following types of autonomic functions: (Niculescu et al. 2019)

- self-management

- self-optimizing

- self-healing

- self-configuration

- self-learning

- self-diagnostic

The emerging of vehicle connectivity has already been considered in the development of traffic management systems. In fact, signal priorities for public transport and emergency vehicles based on vehicle-to-infrastructure (V2I) communications have been in use for some decades already. The more generic concept of cooperative traffic management has been developed during the past few years. Cooperative traffic management has the following basic requirements: (EC 2017)

- Communication – for the purposes of awareness or compliance, the exchange of the appropriate traffic management related data, will be bi-directional.

- Performance – traffic flow conditions will be commonly understood and assessed.

- Collaboration – the actions, from both the public and private sectors, will be complementary, decentralized, and put in place according to pre-arranged agreements.

Cooperative traffic management services will need to be well-orchestrated, as they depend on combined efforts from those involved in the service value-chain, both from the public or private sector. There is a need for scalable and replicable tools to be used across the entire European road network. These tools should provide enough flexibility for city authorities, regardless of their size or mobility policy, and also for traffic managers and road operators, to deploy the

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

services under every possible scenario. The public authorities should preferably play the role of the orchestra conductor and translate their mobility plans into 'standardized exchangeable data' available to the other stakeholders. (EC 2017)

The Enhanced Traffic Management WG of the C-ITS Platform conceptualized a specific set of important tools that need to be developed for digital traffic management plans: (EC 2017)

- classification of roads to be done accordingly to network flow hierarchy
- a geo-fencing mechanism
- establishment of a network performance Level of Service (LoS) specification
- triggering conditions for traffic management actions
- a common operational picture to provide the involved actors with a standard overview and regional context of a traffic situation

The concept of cooperative or Traffic Management 2.0 has been developed by the ERTICO - hosted TM2.0 initiative (TM2.0 2018). An EU research project SOCRATES 2.0 (2018) is developing the interactive traffic management of connected and automated vehicles further based on the same principles. The aim is a win-win-win situation for the key actors in the traffic management eco-system – the road user, the public traffic management centre, and the private service provider (SOCRATES 2.0 2018).

The benefit of the traffic management centre would be that they will be able to substantially optimise traffic management operations addressing a wide range of road users with tailor-made, precise information, utilising new communication channels and sensor/feedback techniques. (SOCRATES 2.0 2018)

Increased cooperation between the stakeholders is fundamental to integrated traffic management. The key actors in this respect the Intermediaries, They are the prerequisite to facilitate the envisioned data cooperation, building a data bridge between road authorities and the service providers, and being integrated into data eco-systems which are already in place – see Figure 7 for the intermediary roles. The new aspects brought by SOCRATES 2.0 (2019) are the following:

- Sharing public & private strategy and goals, common KPI's (Strategy Table)
- Exchanging public & private data and information (Network Monitor)
- A joint 'current (and predicted) state' on the network (Network Monitor)
- A joint 'current state' on roadworks (user feedback and service provider data is fused with roadworks information from the road authority) (Network Monitor)
- Public / private network management (Network Manager)
- Request for network management services to service providers (Network Manager)
- Looking for an 'impact driven' business model (Assessor)

So far, the SOCRATES 2.0 concept has been piloted in a number of locations. The deployments are expected to start soon.

Strategy Table	Create win-win-win / Align public and private goals / Define KPI's / Setup toolbox / Monitor (& redefine) strategic goals and KPI's
Network Monitor	Collect aggregated data from public and private data providers / Fuse data / Predict state of the network / Assess data quality / Respect data agreements
Network Manager	Configuration of KPI's / Create problem state / Identify an effective scenario to solve the problem / Send service requests / Evaluate and improve scenario
Assessor	Validate partner impact / Report on impact and KPI / Virtual rewarding / Data archiving
End user Private service provider	Receive and assess service requests / Activate routes / Measure own impact and inform Assessor
Public traffic manager	Receive and assess service requests / Activate routes / Measure own impact and inform Assessor
Data provider	Providing relevant data

Figure 7. Description of intermediary roles (SOCRATES 2.0 2019).

Challenges

Traditionally, the road operators carry out traffic management by providing information to humans who drive vehicles. With the shift towards providing information to software that drives the automated vehicle this will change significantly. These changes and the impact on the role and responsibilities of road operators were discussed recently in EU EIP 4.2 workshop in Utrecht. (EU EIP 2017)

The main conclusion was that a simple translation of the current messages to humans to messages for machines will not be adequate without rethinking the original purposes of the various traffic management measures. As complex as this may seem, traffic management in a mixed environment may be even more complex when road operators have to consider both (partially) automated vehicles and human driven vehicles. When considering traffic management for automated vehicles, there are two main challenges: (EU EIP 2017)

- How will the nature of traffic management change when it is directed at automated vehicles?

- What is the transition strategy from the current situation to future situations that include mixed traffic?

Today the over-arching goals are 'no casualties, no congestion and no emissions'. The goals are not likely to change with the introduction of automated driving, but the procedures and methods are likely to change. The roles and responsibilities remain the same, and the road authorities and operators have to set the goals for traffic management. (EU EIP 2017)

Traffic Circulation Plans and Traffic Management Plans will need to be deployed differently in the future. Traffic management has to be seen as an integral part of overall mobility management. Automated vehicles should be supported only if they have positive impact on mobility (safety, environment) i.e. by facilitating new services (MaaS, shared mobility, DRT Public Transport). Traffic management has to be approached from collective perspective, but in best case the collective and individual goals (i.e. travel time from origin to destination, length of the trip) can be aligned. (EU EIP 2017; Kulmala et al. 2018)

The transitory phase or mixed fleet situation is predicted to be very long. Therefore, the road authorities need to prepare their traffic management for a situation where some of the vehicles are automated and some are not. The instruments and processes have to be developed

accordingly, to allow for both manual and automated driving. (EU EIP 2017)

Traffic management of automated vehicles is being developed by research projects. TransAID (2020) develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, especially at transition areas, where vehicles change their automation level. MAVEN (2020) develops the management of automated vehicles at signalised intersections and corridors.

2.3.4 Road maintenance

Current Situation

Road maintenance means the continuous, regular road operation and maintenance including road patrols, inspections and minor repairs. These works traditionally face the challenge to be carried out in temporary work zones right next to high-speed traffic with limited traffic management and therefore poses high safety hazards for the workers. Driverless maintenance vehicles and automation of operation and maintenance processes have the potential to reduce this risk tremendously.

Key road maintenance tasks according to NRAs include:

- Inspection of the highway condition and inventory
- Safety patrols and inspections
- Detailed visual inspections
- Cleaning of road surface
- Cleaning and repair of noise barriers, signs and other road furniture
- Debris and litter collection (on highway and off highway)
- Maintenance and minor repair of the road assets and equipment
- Landscaping & grass cutting

These works and services are commonly believed to be necessary to achieve the best possible results with regard to the availability, reliability and sustainability of a highway. They are essential to ensure the safety of the road users and to ascertain that the condition and status of the highway is maintained.

Identification of drivers of socio-technical transition

Many tasks will always need to be done manually by experienced workers. However there are quite a few use cases where automation could already provide safety and efficiency benefits in the near future. Nowadays they are carried out by operational workers who are always at risk due to high-speed traffic right next to them. Supporting them in the most critical operational tasks will take away main safety hazards.

Drivers for developments in road maintenance along automation are two sided. Firstly, the driver to increase safety for road workers and the improvement of operational processes is still important as it already has been in the past. Automation, however, brings totally new opportunities to the table ranging from the use of driverless vehicles for easy road maintenance tasks (e.g. road marking) to the provision of new road condition data by automated vehicles. By complying with the speed limits, the automated vehicles likely also mitigate speeding behaviour of the drivers of the other vehicles in the traffic flow.

Secondly, ODD requirements might result in new or amended requirements for road maintenance standards. One example would be requirements for specific reflectivity levels of road signs which could mean different reaction times for cleaning of road signs. Also general requirements for visibility of signs could mean increased greenery works.

NRAs are generally hesitant to ensure certain condition levels for road marking or cleanliness of road signs for liability reasons. Even with the best road maintenance plans and intervals there are manifold reasons why the required levels are not kept, e.g. severe weather conditions. Also, this would potentially increase road maintenance cost significantly which questionable added value. The definition of machine readability should be harmonized on European level to provide NRAs with but legal certainty but still NRAs do not want to be held liable for the continuous condition of road marking, signs and such.

Challenges

Challenges in this core business field involve the necessity for further development of the technological readiness of the systems and the related legal framework. The digital infrastructure enabling the positioning of the vehicles and according standardized, connected communication with the traffic management centre are key for the safe implementation.

2.3.5   Winter maintenance

Current situation

Winter maintenance is generally part of road maintenance. In many European countries it has such a high level of operational importance that is dealt with separately in this assessment. Weather conditions and the necessity for winter maintenance differ greatly throughout Europe. In those countries with severe winters including black ice and heavy snow this season potentially involves big safety hazard for road users. Therefore, elaborated winter maintenance plans are prepared, tested and adapted in continuous improvement processes.

Identification of drivers of socio-technical transition

This extremely safety critical maintenance task also involves a lot of manpower in rather condensed periods of time but with still potentially long shifts. In some countries, seasonal workers and expensive sub-contracts are necessary and sometimes hard to find for the winter season. It is clear that driverless solutions are desirable and driven by the need to ensure safe mobility also in winter periods.

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

In order to support snow-plough operators who are often tasked with numerous monitoring and operational activities that they need to do simultaneously while removing snow and spreading de-icing agents on the road the use of individual automated functions is tested worldwide. In Minnesota (Arabzadeh et al. 2019; Liao et al. 2018), applications for snow ploughing convoys and lane boundary guidance were tested using DSRC and GNSS-based lane boundary guidance system. Results showed that the positioning accuracy with DSRC was inadequate for providing the plough operator with sufficient information to maintain spacing between two vehicles. The GNSS-based lane boundary guidance system successfully supports plough

operations when visibility is poor and lane boundary cues are limited.

In Japan (Abe 2019) pilot tests have been done on a Hokkaido expressway as well as other roads with similar goals. Highly accurate positioning data from a quasi-zenith satellite were combined with high-resolution 3D map data to provide the operator with additional guidance as well as to track the snow removal progress for the traffic management centre.

Interesting for winter maintenance is also the possibility for vehicles providing wintery road condition data through V2I communication to the TMC. One project in Germany by Mercedes Benz is testing the provision of data on snowy or icy road conditions through electronic stability control (ESC) and anti-lock braking system (ABS) to enable more efficient winter maintenance planning (Next Mobility News, 2019).

Challenges

Technical complexity of the driving task itself due to limited visibility as well as the necessary ever-changing strategy adjustments of salting amounts and snow plough shield adjustment make this use case particularly difficult. High-level automated or even driverless snow ploughs for motorways are therefore a distant vision. In the meantime the step-by-step integration of automated functions is tested with promising results in projects worldwide. Doubts of the regulatory barriers and adverse weather capabilities remain a key challenge.

2.3.6   Traffic information provision

Current situation

The aim of the traffic information provision as part of traffic management is to affect road user behaviour to improve safety, sustainability and efficiency of road transport system. The focus is to enhance safety of road traffic, inform about the status of the road network and traffic and thereby, enable mobility of people and goods, and at the same time decrease or minimize pollutions and emissions caused by road traffic.

Road operators are taking care of information provision in collaboration with several stakeholders and delivery channels. In many countries, the Traffic Management Centres (TMC) are in key position in organizing local networks of actors. TMC acts in cooperation with local stakeholders like police, rescue service, maintenance service, meteorological institutes, information service providers and media.

The information is changed between the stakeholders to enhance effective traffic management. The messages, however, are also delivered to ordinary road users. Traffic information is largely based on real-time data on traffic for example from the road side units. The status and situational picture of the whole road transport system including circumstances is mediated with new communication technologies, and thereby, regarded as part of ITS.

The ITS action plan and the ITS directive of Priority actions (2010) followed by the delegated acts by EC defined information categories and prioritized them and responsibilities of actors in delivering the information. Procedures for the provision of minimum EU-wide traffic information for 'real time traffic information' and 'safety related traffic information' have been developed. Other examples of information types are 'secure truck parking information', 'cooperative ITS' and 'multimodal travel info and route planner'. The road operators have several roles in traffic information provision depending on the situation; they act as road authorities, data providers and they can also be service providers.

To improve security and access to information, NRAs have supported message standardisation for different phases in the traffic information provision - from detection of a

traffic event, through pre-processing and provision to presentation to the end user. DATEX II in particular, is designed for information exchange between traffic management centres, traffic information centres and service providers. Several channels to deliver the information are in use (radio, variable message signs, cellular networks etc.). Due to several different type of stakeholders in the field, compatibility has been concerned and enhanced for example by the Traveller Information Services Association (TISA 2012).

Currently, development projects of traffic information are very much focusing on C-ITS corridors where the aim is been to provide continuous C-ITS information services in Europe (C-ROADS Platform). Several types of warning such as hazardous location warning; slow vehicle warning, stationary vehicle warning, emergency brake light, emergency vehicle warning, road works warning, and in-vehicle signage/information are being tested. The C-ITS corridors may also act as paths to and test sites for demonstrating connected and automated driving.

Identification of drivers of socio-technical transition

Societal drivers

Safety expectations towards highly automated driving are high. This motivates investments enabling automated driving and enhances deployment.

The nature of car driving as an activity is changing along with increasing automation. The possibility to utilize the time of driving in other activities may be tempting for general public and thereby enhance acceptance of automation in road transport and thereby implementation decisions.

Demand for equity and accessibility are stressed in the society; enhancing automated driving can be motivated as a measure contributing to these goals. Automation probably means changes in land use, for example need of parking space and the space could be used to improve quality of live and wellbeing in cities.

Technical drivers

As stated above in the chapter of traffic management and control, the road operators traditionally carry out traffic management by providing information to humans who drive vehicles. With the shift towards providing information to software that drives the automated vehicle this will change significantly.

The main conclusion was that a simple translation of the current messages to humans to messages for machines will not be adequate without rethinking the original purposes of the various traffic management measures. As complex as this may seem, traffic management and information provision in a mixed environment may be even more complex when road operators have to consider both (partially) automated vehicles and human driven vehicles.

Connectivity is assumed to improve the quality of information services as several data sources can be utilized effectively. Connectivity will enable increased participation, collaboration between drivers but also collaboration with service providers and road operators. In practice, information exchange may be automated via ITS infrastructure owned and maintained by road operators.

The quality of traffic management services are assumed to be improved due to changes in information, too. Furthermore, the new networks may affect traffic management realised by road operators in more fundamental ways. The direction of the change could be from centralized information delivery and management towards self-organizing networks in traffic. This, however, assumes quite significant penetration of connected vehicles. The improved quality of traffic information is seen as a driver for changes in traffic management.

Design drivers

Infra-based information channels (VMS etc.) should be recognized as specific design objects in the automated road transport. Generally, it is assumed that before full automation, as in the scenarios for years 2030 and 2040, availability and quality (accuracy) of information will be highlighted.

Automation changes driving as an activity. High automation implies that during automated driving, distraction would no longer be a severe problem, but there would be more room for delivering on-board information.

When designing automation, information is needed to support the automated system. It is shown in other domains with long traditions in automation that it is important to keep the operator in the loop in the activity even if it is automated (e.g. Kaber & Endslay 1997). The information provided by road operators is assumed to have an important role in delivering real-time information to support situation awareness of drivers in 2030-2040 automation scenarios in particular. Real-time information becomes critical in driving situations where automation cannot be fully utilized; for example, in case of an incident or in adverse conditions associated with discontinuity of automation support (outside ODD). Furthermore, well-designed real-time messages would support situation awareness more generally, including detection of objects in the environment, interpretation of small but potentially critical signals, and anticipating exceptional situations.

Automated driving assumes that road transport system is rule-based. However, in some situations even safety critical messages may be needed.

Challenges

The most important societal challenge currently is the climate change, and hence the aim to reduce CO_2 emissions significantly towards the goal of carbon neutrality has come to the forefront. It has been assessed that automation may have negative rebound effects in this respect, which calls for actions also regarding information delivery. Not only tactical type of information contents, typical for current activities of road operators, but also more strategic type of information which would focus on selecting sustainable modes of travelling, reducing CO_2 emissions etc. should be delivered. In this, higher level goals such as improvement in quality of life are highlighted.

User acceptance and trust of people on automation are critical in for the aim to build automated road transport. This also emphasizes role of more general information on planned changes, how they are going to be implemented, and how for example security is taken care (OECD/ITF 2018).

As indicated, safety expectations are high. The acceptance of crashes with automated vehicles may be lower than in manual transport system.

Many positive impacts of automated driving presume connectivity, but it may take quite a long time until sufficient penetration rates are achieved. In case connectivity is seen important for all user groups (pedestrians, cyclists), the goal is even more challenging.

Management of physical and digital infrastructure for automated road transportation is assumed to include new demands also for information delivery:

- Information on availability and coverage of V2I infrastructure for automation

- Information of pothole occurrence (severe road damages on the main carriageway)

- Information on use of hard shoulder (for hard shoulder running or as an emergency stop area for automated vehicles)

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

2.3.7   Enforcement

Current situation

The aim of enforcement is to support safe and efficient road transport, and to deter antisocial and criminal behaviour. The major targets of enforcement are preventing excess speeds, driving while intoxicated as well as such negative behaviours as violating red lights. In the context of road operators, important aspects of enforcement are supporting access restrictions and promoting compliance with weight restrictions and thereby contributing to the reducing harm to road infrastructures — road surfaces as well as the integrity of bridges and viaducts.

Enforcement is carried out in close collaboration with police that has the main responsibility of enforcement according to the principles decided in each country. The enforcement policy is developed together with decision makers, police and road authorities. The role of the road operators is to provide and maintain infrastructure and equipment such as speed and red light surveillance cameras or speed enforcement posts, while the police is responsible for managing the data and actions directed at the road users.

NRAs set the speed limits following the policies adopted, decide the locations of speed cameras and stations, implement and maintain them. However, there may be differences between countries in the details of how cooperation is organized, and in the interfaces between police officials, road operators and potential other service providers.

Identification of drivers of socio-technical transition

Societal drivers

With increasing automation, the role of enforcement is assumed to diminish or the focus changed. In automated driving, the human driver would no longer be in charge of selecting the driving speed but the speed choices would be made automatically based on digital map and other inputs. As a basic requirement, the posted speed limits would not be exceeded. From the road user perspective, the role of on-road speed enforcement would be smaller. Still, the speed limits would be agreed nationally and it would be necessary to confirm that vehicles are obeying the limits, including time-limited and dynamic limits.

Acceptance of enforcement may increase as the target would be no longer the road user behaviour but rather the vehicle behaviour. The responsibility of road operators may be highlighted as the provision of data regarding the speed limits to be used by the automated sensor or knowledge-based systems of the vehicles.

The legal aspects and responsibilities of different parties should be clarified. It is likely that the regulations concerning the spacing and headways between moving vehicles on the same lane may need to be changed. The headways facilitating improved throughput on roads for example with cooperative cruise control and platooning are below the thresholds currently permitted on the roads in many if not all European countries.

Technical drivers

Automated vehicles are assumed to set the speed automatically. All automated driving systems will have to obey prevailing speed limits however they are implemented – fixed, conditional (e.g. for a specific vehicles type), variable by time of day and dynamic. The availability of reliable speed limit data regarding the ODDs is important, and provision of it will remain the responsibility of the road operators.

Also driving against red light can be controlled by automated functionalities, as can other violations, e.g. of access restrictions such as the use of high-occupancy vehicle lanes.

Design drivers

The automated road transport needs to be designed in such a way that all parties, including

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

human operators, i.e. "users in charge", are aware of their responsibilities. The users should know that the vehicle they are using is operating in accordance with the regulations and limits of the ODD. One critical element of situation awareness is a good understanding of the capabilities and status of automated control of the car.

Challenges

The focus in enforcement would be changed from individual road users towards vehicle behaviour. At the same time, it could be the case that in the future vehicles are required to have an external indication when a vehicle is being driven by an automated driving system. This would make enforcement easier.

There will be high quality and coverage demands for the speed limit information. The rules and procedures to set the speed limits may need to be renewed to respond to the properties of automated vehicles.

Automated vehicles will have to be aware of access and weight restrictions. The ODD for a freight vehicle cannot be such that it is able to drive over a bridge or viaduct with a weight restriction that it will exceed.

2.3.8   Road user charging

Current situation

In many countries privately financed and operated motorways form, based on long-term concessions, an essential part of the national highway network, while in other countries the networks are fully under control of the national road authorities. As automated vehicles may require additional investments in the tolling systems, legal measures may be needed regarding the concession agreements.

Road user charges on the entire EU road network, urban and interurban motorways, major and minor roads, and various structures, such as tunnels or bridges, and ferries, are ruled by the Directive (EU) 2019/520 (European Parliament 2019) on the interoperability of electronic road toll systems (EETS – European Electronic Toll Service). The Directive, and the Implementing and Delegated Acts based on the Directive, also stipulates allowed technologies of the tolling systems, in cases the Directive apply. Electronic road toll systems which require the installation or use of on-board equipment (OBE) shall, for carrying out electronic toll transactions, use one or more of the following technologies: a) satellite positioning (GNSS), b) mobile communications or c) 5,8 GHz microwave technology (DSRC). In practice, DSRC is still the dominating technology in the communications between the OBE and the roadside units while GNSS is considered to be the future. Mobile communication is used for communication between the OBE and the central system. The Directive does not apply to a) road toll systems which are not electronic or b) small, strictly local road toll systems.

Identification of drivers of socio-technical transition

Societal drivers

Due to the needs to mitigate climate change and also congestion, the use of road use charging will likely increase especially in and around large cities, based on the good results from the deployments in Singapore, Stockholm and London (e.g. Lee 2018). Road user charging may also be further developed due to the need to compensate reducing tax revenues from fossil fuel sales by for instance driving distance based kilometre taxes.

Technical drivers

Most of the tolling systems are still based on DSRC, but there are already some extensive GNSS based systems and there is a clear trend towards those. Furthermore, some automatic licence number recognition based toll systems exist and this technology is frequently used for

enforcement of road user charges both in DSRC- and GNSS based systems.

The Directive also provides for an open tolling market in the sense that the toll charger (TC) role and the payment service provider (SP) role are separated. On a European level EETS Service Providers (ESPs) can be accredited and may then provide tolling payment services all over Europe. This is already emerging.

In GNSS based systems there exist only virtual toll plazas, if any. Consequently, properly equipped automated vehicles can behave as traditional vehicles in these systems (e.g. German and Belgian HGV charging systems).

Modern DSRC tolling systems are based the "multi-lane free-flow" principle. In these systems properly equipped automated vehicles can also behave as traditional ones.

Challenges

There are still quite many older toll systems in Europe based on large toll plazas with barriers providing the enforcement. These systems often provide for many payment options such as cash, card or DSRC, often on separate lanes. At these toll plazas physical rearrangements may be required to provide for smooth tolling of automated vehicles. In some cases, free flow lanes might already have been added for DSRC users, to which automated vehicles can be guided.

There could also be a need to set up a road charging system to promote higher level automated driving in order to reach higher adoption and use rates for automated vehicles. The development of such charging schemes for different operating environments and transport systems will be quite a challenge. As a comparison, Norway has achieved an impressive penetration level of electric vehicles by means of heavy tax subsidies and other complementing measures such as zero toll fees, free use of public transport lanes etc.

When setting the level of road use charges for automated vehicles, a potentially higher safety has to be weighed against e.g. the extra investments required by the automated vehicles. These may include changes in the tolling infrastructure and central system, lane re-arrangements or other infrastructures such as high-resolution localisation augmentation support or lay-bys e.g. to break up platoons.

2.4 Planning, building, heavy maintenance

2.4.1 New roads planning and building

Current situation

Differences of road networks between countries are obvious, the total road length and type of roads, their equipment, the traffic regulation, economic wellbeing, the weather conditions, and also the responsibilities of NRAs are manifold. However, new road construction and strategic development of necessary road networks has been done successfully throughout Europe in the past decades. This means that most countries have their necessary road network more or less in place, shifting the focus and monetary resources from new road construction to rehabilitation and maintenance of the existing roads. Unlike emerging cities and countries (e.g. Arab region) EU countries and their road networks are not newly designed on the drawing board providing the possibility for perfectly suitable infrastructure requirements.

It is crucial to consider this fact as the planning of new roads obviously needs to consider and make provisions for mixed traffic and CAD. These new roads however will only be a very minor part of the network used by AVs. Therefore, it is even more important to define standards for rehabilitation and extensions of existing roads considering the necessary equipment. This way road networks will be upgraded step by step as part of the continual asset management and

heavy maintenance program.

Identification of drivers of socio-technical transition

So called infrastructure support levels for automated driving (ISAD) are currently being developed in the project Inframix (Carreras et al. 2018). This provide a good basis but will need to be further defined to provide very clear guidelines for necessary digital and physical infrastructure a like. The ISAD levels are meant to describe road or highway sections rather than whole road networks. In order to structure the various means of support that infrastructure can provide towards automated vehicles, 5 levels are proposed which are based on the idea of the SAE levels for vehicle capabilities. New road planning in the future will probably need to involve the assessment of the new sections and dependent on their importance and segment a categorization in those ISAD level. The first driver for new requirements for new road planning should result from those ISAD level requirements.

The second driver are once again the ODD requirements as described in great detail in D4.2 of this project (Ulrich et al 2020). Dependent on the respective NRAs strategy and willingness to support and widen the ODDs of different use cases, these ODD requirements will result in further development of design guidelines for new roads planning. Both ISAD level requirements and ODD requirements should be applied equally not only for new roads planning but also for rehabilitations.

Challenges

Challenging is in particular the cost impact of such new requirements for which details and actual necessity are not entirely clear at this point and ever-changing with the ongoing evolution of sensors and AV technology. Prioritization in terms of road types and relevant routes will be crucial based on what NRAs can afford to do. However, new road construction will make the integration of digital infrastructure much easier compared to upgrades during rehabilitations of existing roads. NRAs are advised to use this opportunity and plan the digital infrastructure requirements defined as part of the ISAD levels as well as the ODD requirements.

Some countries already started to develop such design guidelines for infrastructure (e.g. U.S. DOT 2018b; Zencic 2019) but also admit that it is an ongoing approach in particular facing the challenges of limited, concrete exchange with CAD developers in terms of ODDs.

One element that would have 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. Design guidelines should therefore provide indications in which areas, road types, use cases and/or traffic volumes this could be a recommended solution.

Relevant for new roads planning will also be the shift of needs for stationary traffic. While needs for parking spaces might decrease over time, additional areas for deliveries of all kinds and sizes will potentially increase. What bus stops are nowadays might need to be multi modal switching hubs in the future providing variable room for traffic mode switches.

One other element of new road planning and construction is the application of the BIM (building information modelling) methodology to ensure the parallel development of a so called digital twin of the new road that includes all necessary design, material and operational data for each asset. This will also provide the basis for NRA's information exchange and provisions for HD maps.

2.4.2   Road works management and planning

This chapter will focus on the traffic management and planning of road works. Planned road works as part of routine maintenance works, rehabilitation or even new roads are not only core business of road operators but also heavily affect traffic flow and road safety requiring close cooperation with traffic management.

Current situation

There are six different stages in the road works management process as presented in Figure 8. In the roadworks design stage, the road operator is looking to balance three key objectives: safety, customer service and delivering the road investment strategy. Secondary consideration is then given to broader objectives such as environmental outcomes and encouraging economic growth. The process differs for major projects and operations. In the Netherlands, Rijkswaterstaat adopts an approach to network management designed to improve road user satisfaction, including 'Smart Planning', a process that prohibits roadworks on diversion and parallel routes. Some road operators have 'customer-centric' guidelines for design e.g. acceptable delay times per 100 km, amount of roadworks per 100 km. (CREDO 2017).

The scheduling process is required to provide visibility of planned roadworks to all stakeholders (including the road operator, contractors, local authorities, and statutory undertakers such as utilities and infrastructure operators), balance flexibility vs. certainty in booking roadworks slots, identify where planned roadworks overlap with or disrupt other roadworks, and manage these clashes effectively. (CREDO 2017) There are several ways for fixing the slots, and the evolution is towards a system optimising the whole network performance rather than optimising at individual roadworks. A lane rental fee can be charged to contractors to ensure quick roadworks implementation and thereby minimise the slots' duration and thereby disturbance to the traffic (DfT 2019).

Figure 8. The six stages of the road works management process (CREDO 2017).

In the third stage, the road operator likely adopts a formal approach to overseeing major projects, whilst taking a more hands-off approach to operations roadworks, relying on the lead contractor to oversee and manage works. In both cases there is limited specific measurement of roadworks delivery versus the plans. A number of road operators adopt a practice of penalising contractors for overruns, often through lane rental (DfT 2019) and/ or penalties. (CREDO 2017).

 The fourth stage, continuous improvement is a function of several different aspects: learning from past experience, sharing best practice/learning from others, and fostering innovation within and into an organisation (CREDO 2017). Federal Highways Administration in the US compiles a Best Practice Guidebook (FHWA 2020) which facilitates sharing and incorporation of best practice across all US states.

The communications (stage 5) should consider the anticipated scale and impact of the roadworks, relevant stakeholders to engage, appropriate communications channels and required messages. In the Netherlands, the Minder Hinder model has effective customer communication' as one of its core pillars, and it places emphasis not only upon conveying the facts around the scheme but also articulating the rationale for what is going on within the roadworks and what the outcomes will be, in order to increase user tolerance. The Spitsmijden programme uses particular incentives to proactively drive positive change in road user behaviour around roadworks. (CREDO 2017)

The sixth stage, performance management has evolved continuously. There is development towards a roadworks focused performance management process, which would include traffic flow KPIs, customer satisfaction measures and other metrics aligned to the road operator's objectives and gathered for specific roadwork events. (CREDO 2017)

Identification of drivers of socio-technical transition

Design drivers

From the design perspective, roadworks should be planned and implemented in a way that makes them easy for the vehicle drivers to negotiate in a safe manner. While the markings have been harmonised to a large extent both in the European and global scale, there still seem to be many differences between local and national practices in Europe.

In the advent of connected and automated vehicles, the calls for harmonisation extend 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.

Technical drivers

Connected vehicles will enhance at least the processes in stages 5 and 6, to be considered already in stages 1 and 3. This has already been piloted on the Cooperative ITS Corridor Rotterdam – Frankfurt/M – Vienna (Figure 9). There connected vehicles receive information and warnings of the roadworks via short-range and longer-range communications while at the same time providing probe vehicle data (PVD), also for the use of road works management (Verweij 2017).

Automated vehicles are not yet considered in the road works guidelines, but they will certainly have an impact in stages 1, 2 and 3 due to the 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 provide new tools for ensuring roadworks safety in stage 3. Connected

and automated vehicles may also be able to provide data to be used in stages 4 and 6.
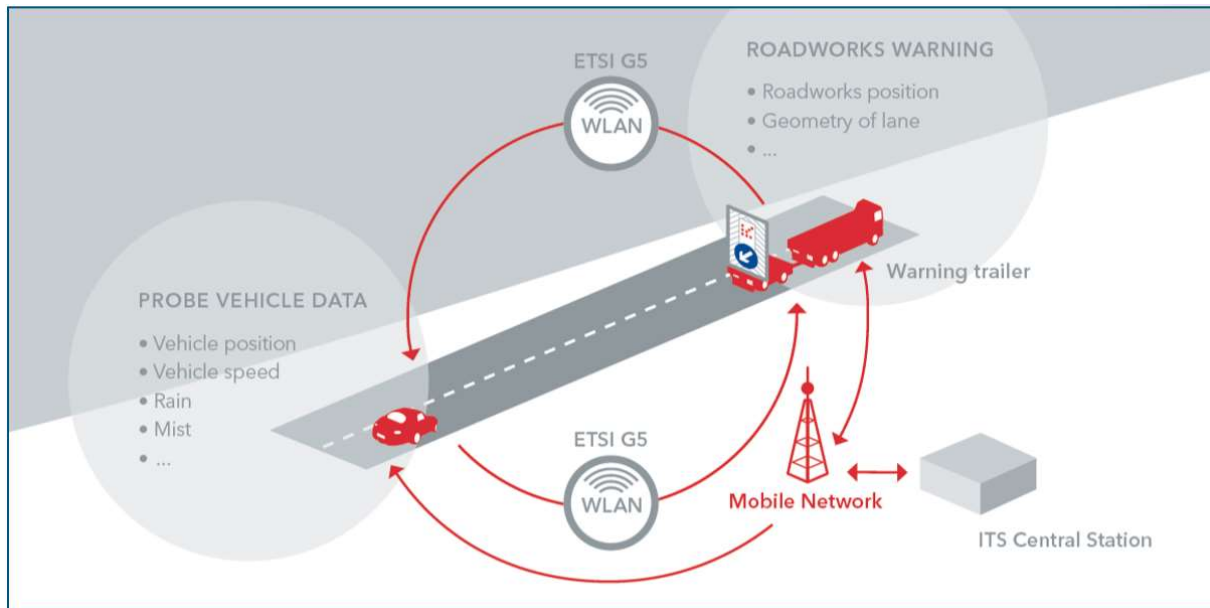
Figure 9. The roadwork warning concept of the C-ITS corridor (Verweij 2017).

Challenges

Road works planning of the future therefore goes beyond picking right time slots and planning the local traffic management layout. The standardized information exchange on location and layout together with defined communication protocols have to be compulsory. Guidelines for necessary sensors in road work zones need to be developed and lane layouts, temporary marking and other guiding elements described in greater detail.

2.4.3   Heavy maintenance planning

Current situation

Key road networks have been successfully provided throughout most of Europe in the past decades with a shifted focus to rehabilitation and maintenance of the existing roads. Infrastructure asset management and asset deterioration monitoring are becoming more and more important business areas for NRAs throughout Europe.

Identification of drivers of socio-technical transition

Many asset monitoring and management tools are available but all require continuously good data quality and equally important sufficient historic data to enable sound deterioration forecasts. One technical driver in heavy maintenance planning along automation is therefore the improved provision of condition data. Initial ideas involve the automated provision of infrastructure condition data through vehicle-to-infrastructure (V2I) communication both ways. Various C-ITS projects tested and provided solutions for communication of condition data into vehicles which provide a basis for the planning of operational highway works. The sensors of

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

connected and highly automated vehicles will be able to provide a lot of data of the traffic and environmental conditions along their route. Such data would be extremely useful to the road operators and traffic managers. Challenging is though that the vehicle and information service industry is not willing to provide their collected data for free via connected and/or automated vehicles. The only type of data, which also the industry needs to share according to European legislation is safety-related information. This information, detailed in eight information types, has to be shared on the basis of the delegated regulation for road safety-related minimum universal traffic information free of charge to users (EC 2013).

Future ambitions involve also the collection of road condition data like cracks, rutting or skid resistance facilitating sensor technology of highly-automated vehicles through V2I communication. However so far it remains unclear if CAV sensors will be suitable for the provision of condition data. Other examples of automated condition data provision include new concepts utilizing drones for difficult to access infrastructure assets like high bridges, gantries or tunnels as tested in projects like e.g. Riskmon (Bladescanner, 2019).

Challenges

The provision of data always goes hand in hand with security and privacy challenges. This also holds true for the provision of road condition data through connected vehicles. Also the provision of road condition data has not been very high up on the agenda of vehicle manufacturers who want to solve their many challenges on the way to automated driving first. There is no direct incentive for the industry to develop integrated systems using the available car sensors for road condition monitoring. However, as the ODDs of highly automated vehicles likely also relate to the road condition, the situation may change in the near future

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

3   Impacts of highly automated driving on core business

This chapter investigates the impacts of highly automated driving on the socio-technical regime i.e. the core business of the national road authorities. The impacts are classified into four domains. The first one deals with the impacts on objectives and mission, which reflect the "policy" dimension in Geel's (2011) model. The second one of impacts on operations and use of technologies is related to the "technology" dimension, while the third one of impacts on NRA role reflects the dimensions of "culture", "markets", and "industry". The fourth one describes the changes in the legal framework of NRA business.

3.1 Physical Road infrastructure

Impact on objectives and mission

If NRAs want to enable the potentially positive effects of CAD in terms of safety, traffic flow and such they are advised to make appropriate provisions so that their infrastructure supports the ODD of those use cases with most promising impact on safety, traffic flow and sustainability. Most required infrastructure support will be on the digital side but also physical infrastructure alterations should be very carefully selected. In a recent workshop on ODD related infrastructure requirements as part of the ITS world conference in Singapore (Vreeswijk 2019) it was agreed that it is necessary to try to limit the dependence on physical infrastructure because of the cost.

So far the physical infrastructure has been the key resource of NRAs. On the way towards CAD the European focus is clearly on enabling connectivity to ensure safe implementation of AVs. Hence, reliable and secure data provision will become more important. This could mean a real paradigm shift for NRAs towards digital infrastructure and data provision if they still want to play an active role in traffic management. The physical infrastructure will always remain a key pillar with the largest monetary needs but in the future this will be accompanied more strongly by the digital infrastructure business field.

Impact on operations and use of technologies

Impacts to the physical infrastructure are expected to have two main sources. Either, new CAD use cases such as e.g. truck platooning could have an impact on durability and serviceability purely due to their operation. There is likely to be additional impact on physical infrastructure that result from the ODD requirements of such new CAD use cases. 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 through technical standards. Amendments therefore need to be well thought out.

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. Technical consequences and resulting impact on technology are further described in detail in deliverable D4.2 (Ulrich et al. 2020).

Information on ODD requirements from CAD developers unfortunately is still limited due to market competitiveness excuses of CAD developers. Therefore, the identified ODD requirements are based on MANTRAs multi-stakeholder workshops and expert views. In any case prioritization in terms of road types and relevant routes are crucial based on what 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

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

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.

In MANTRA Deliverable 3.2 (van der Tuin et al., 2020), a microsimulation study investigated the impact of highway autopilot at weaving sections, entry ramps and exit ramps. It was shown that the length of the taper lane did not significantly influence the travel time delays experienced during lane changing, unless it was very short (i.e. <50m). However, it was considered that vehicles have a good sight on the traffic on the highway while merging. In general, the lay-out of ramps on highways possibly do not need to be adjusted due to the introduction of AVs, but the visibility might need improvement depending on the vehicle sensors and software.

The overarching recommendation to NRAs is however to analyse their networks and prioritize where deployment of CAD use cases is most suitable and sensible to start adaption to the physical infrastructure only there. A structured approach dealing with the impact to physical infrastructure will be the development of design guidelines for planning of new roads as well as for upgrades of existing ones. Some countries have already started to develop such guidelines for infrastructure (e.g. U.S. DOT 2018b; Zencic 2019) but also admit that it is an ongoing approach in view of the limited, concrete exchange with CAD developer in terms of ODDs. Here it can be noted that the NRAS are not active participants in the on-going discussion and standard-setting at a world level on ODDs and functional requirements for automated vehicles, taking place at UNECE WP.29, the World Forum for the Harmonization of Vehicle Regulations, and its sub-groups. That means that, while there are likely to be substantial impacts of automated vehicles on road operations, the NRAs are not present at the table where substantive decisions are being made on the specification of automated driving systems.

Minimum risk manoeuvres could cause a lot of safety and throughput problems for the road operators, unless such manoeuvres can be accomplished in a safe and efficient manner considering the road operator concern. The alternative would be to prohibit the use of highly automated vehicles in automated mode on safety- and throughput-critical road sections.

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 CAD and recommendations rather effect the digital part, these hybrid forms are allocated to the digital infrastructure.

Impact on NRA role

So far physical infrastructure has been the key resource and business field for NRA and hence defined their role. The quality of NRAs was mainly compared based on the condition and quantity of the physical infrastructure managed by them. The main task was building, maintaining and operating this physical infrastructure. In other words if NRAs are compared to production industry their sole key product has been the physical infrastructure.

With the introduction of ITS and tolls the role has shifted from sole provision of physical infrastructure to a service provider. With the increasing importance of data provision and the interaction with other transport modes this shift progresses even further. NRAs will be in competition and cooperation at the same time with mobility and map providers.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Impact on legal framework

Physical infrastructure is regulated through manifold European and local technical standards. As explained CAD introduction will make it necessary to audit those standards and provide them with updates for road categories and routes where CAD are introduced. This includes structural bridge standards (where deployment of use cases of high capacity vehicles or truck platooning are foreseen) as well as harmonized standards throughout Europe for the machine-readability of the whole road guidance system. International/European standardisation is deemed critical in terms of machine readability but not in terms of harmonized design of road markings and signs. However NRAs shall not be held liable for the condition of road marking as this is subject to manifold factors ranging from maintenance to adverse weather. CADs therefore will need to be able to react accordingly if road markings and other guiding systems are suddenly not in accordance with their ODD requirements. A combination of physical and digital "guiding information" is expected, which will need to be regulated also legally in cases of discrepancies. (Expert workshop, Vienna, 10.09.2019)

3.2 Digital road infrastructure and ITS systems

Different dynamics are in place concerning key NRA challenges in different regions and cultures in Europe; specifically the role of digitalisation on strengthening a country's or region's economic competitiveness in a global innovation system is easier recognised in some cultures. Integration of ever new capabilities, human resources and innovative technologies is increasingly seen as dependent on an effective local digital ecosystem. Some NRAs haven't had any explicit mission of fostering a country's economic competitive capacity (beyond operating efficient road networks). This might change.

Impact on objectives and mission

NRAs will see a rather diverse ecosystem of dynamically reorganising value networks and service provider partnerships. To maintain one's own value network or mobility service will quickly become only one of multiple options. Striving to become an innovative and agile partner in these ecosystems will to a certain degree depend on the mission readiness to address the needs of a variety of stakeholder groups.

The trade-off between risk mitigation by means of rather conservative deployment strategies and shorter digital innovation cycles with strong positive spill over effects into regional economies has the potential to request adaptation in NRAs' objectives and mission statements.

The NRAs are anticipated to face requests into how they are proactively contributing to a sustainable and effective European data ecosystem along the lines of the European data strategy (EC 2020).

Improved and new narratives are needed for NRA's core business and in negotiation with their governmental partners to help overcome false dichotomies like choosing either automation or new green deal, or either automation or safe and inclusive motorized road transport for all.

Big tech giants have already entered the connected and automated vehicle ecosystem affecting the mission of objectives of the OEMs. An interesting question is whether the big tech giants will also make a considerable entry to the road network operation regime somehow affecting the mission of the NRAs.

Governments and road authorities cannot work like a start-up, and might even find it rather challenging to cooperate with start-ups. At the same time, cities have a already a long history working with start-ups, also in the mobility domain.

Automation holds not only opportunities, but also many fears. Fear blocks people and organisations from trying new things. Similar cultural challenges have been witnessed in traditional banking system vs entirely new financial technology stakeholders, including obvious lessons from banking legacy IT vs newest financial technology platform IT systems.

Impacts on operations and use of technologies

Digital infrastructures are often costly to deploy, operate and maintain. Hence, sharing of digital infrastructures is an attractive option, also in bundling and pooling of digital road infrastructure to reduce deployment cost and or to achieve critical data rates especially in early vehicle connectivity penetration stages.

Automated driving on open roads is not only automation technology – it involves agendas such as digitalisation, end user acceptance, operational mode of passenger cars and their respective assistive systems, availability of communication for safe cooperative manoeuvring including automated trucks and semi-automated passenger cars. Within automation, all stakeholders will likely need entirely new forms of data strategy and cooperation strategies on data fusion. There could be potential synergies and merging ideas between future low-air traffic control centres and road-based traffic control rooms. It is not entirely clear, how this would impact key NRA activities.

The impacts related to HD maps have been described in detail by the DIRIZON project (Malone, et al. 2019). The road operators are expected to provide data for the HD maps to road map and service providers directly or via national access points (see Figure 10). The profiles, formats, structures and procedures needed to handle data streams are to be specified and tested in agreement with other stakeholders, and especially the HD map providers.
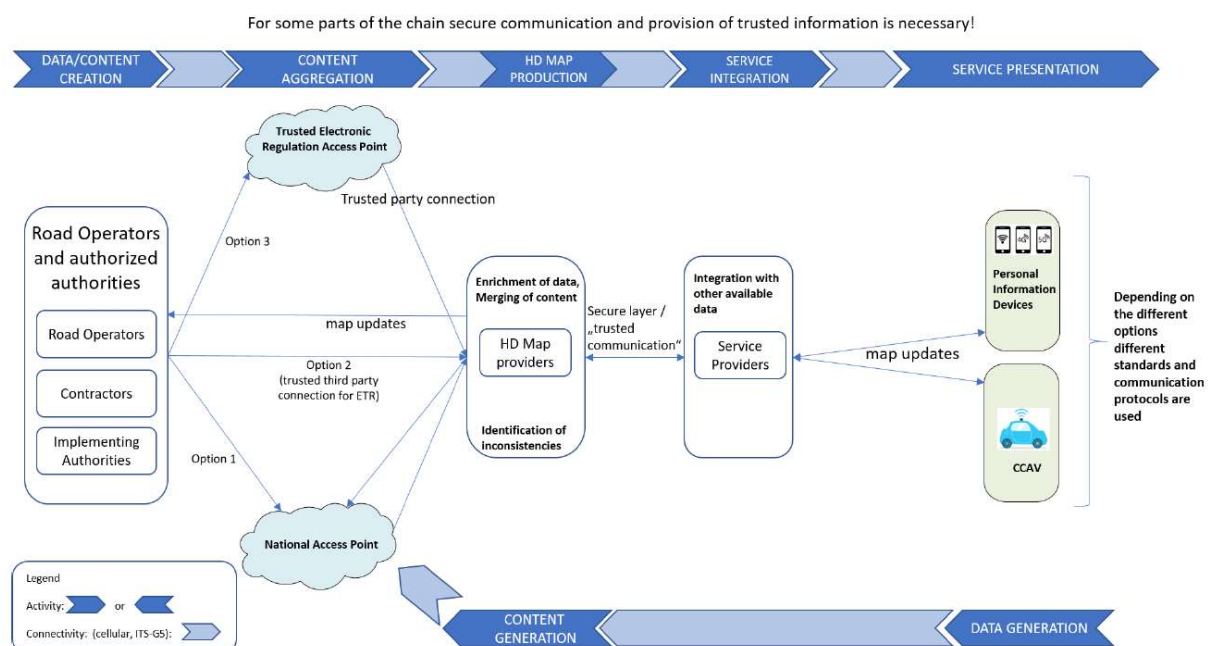
Figure 10. The HD map process flow diagram (Radics et al. 2020)

The road network data will need to be digitized including the any landmarks supporting accurate vehicle positioning. This will be carried out by HD map providers, but also road authorities and road operators may want to have it done for themselves as HD maps of the roads and their (sub-)structures can be regarded as a key asset of the road operators with regard to their core business. Outsourcing such a key asset to external service providers will carry considerable risks. By 2040, 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).

Specific attention needs to be given to including ODD attribute related data in the HD digital maps especially for physical infrastructure attributes, which may not be provided by the road operators throughout the road network due to their high costs. Examples of such are, for instance, wide shoulders, safe harbours and game fences. The availability and location of such attributes is essential for the highly automated vehicles in order to determine the existence of their ODD.

Highly automated 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). Satellite positioning is the basic positioning solution, and it has been shown to reach the desired 5 cm accuracy when supported by RTK (Real Time Kinetics) land stations. Such or similar stations should be provided especially in challenging environments such as northern latitudes and mountainous areas. They could also be integrated with the 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.

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.

Other elements than those mentioned above could be regarded as part of the digital infrastructure for automated vehicles or at least the management of the transport system for highly automated vehicles. The concept of virtual transport system or a real-time 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.

Impacts on NRA role

Artificial intelligence, digitalisation and the versatile big data from fixed and mobile sensors have the potential to automate many of the processes and operations of the NRAs and other road operators. They might also affect the road of the road operators. This relies on whether and how these new technologies can be effectively absorbed by NRAs. Absorptive capacity is seen as influenced by an innovative local digital ecosystem. A realistic picture would show that most road operators currently rather buy and deploy information technologies that have been around for some twenty years. This has partly been related to safety critical infrastructures, but also to the rather limited roles of innovation in every day purchasing routines.

The big tech companies have already taken steps into the mobility domain and increase their roles in the digital mobility ecosystem, especially with regard to smart cities. In order to maintain the NRA's role in network operation and traffic management requires that NRAs are active in the digital mobility ecosystem and proactively maintain their coordinating and supervisory role in their domains.

Impact on legal framework

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 NRAs 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.

The issues of human decision making also related to road operators' own ITS, and especially the processes and operations in traffic management/control/information centres. The traffic centre processes will be increasingly automated, and by 2030 many traffic management systems are capable of 24/7 operation without any human involvement (Niculescu et al., 2020). This will be beneficial for the cost-efficiency of traffic centres and traffic management, but may need changes in the legal framework for traffic management nationally in many countries.

There is likely a need for a mandate for road operators to make their existing data available for HD road map purposes. There could also be a need for the OEMs and fleet managers to provide feedback about the anomalies in HD maps detected by their vehicle fleets. The increasing provision of digital infrastructures to ensure the ODD for automated vehicles will likely also result in increasing number and importance of product liability issues.

Legal issues may arise related to serving different stakeholders with different service levels and mobility priorities. Without this possibility, most innovative and successful operators would pick partners that can provide this differentiation in a dynamically evolving mobility service chain.

3.3 Operations and services

3.3.1   Incident & event management

Impact on objectives and mission

Automated driving is not expected to have any major impacts on the objectives and missions of incident and event management. The importance of incident and event management in road network operation will remain high for NRAs and other road operators.

Impacts on operations and use of technologies

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 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.

Impacts on NRA role

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.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Impact on legal frameworks

The delegated regulation c) (EC 2013) already requires the stakeholders to provide access to the following types of safety-related data:

> (a) temporary slippery road;
>
> (b) animal, people, obstacles, debris on the road;
>
> (c) unprotected accident area;
>
> (d) short-term road works;
>
> (e) reduced visibility;
>
> (f) wrong-way driver;
>
> (g) unmanaged blockage of a road;
>
> (h) exceptional weather conditions.

Especially data types b), c), and g) are directly related to incidents, and cover by far most types of incidents. Hence, the legal framework exists, 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 highliy 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.

3.3.2   Crisis management

Impact on objectives and mission

Highly automated driving is not expected to affect the objectives and mission of crisis management.

Impacts on operations and use of technologies

The improvement in the crisis management processes and procedures due to connected and automated driving are similar to those listed earlier for incident and event management.

Impacts on NRA role

Crisis events affecting the road network are very much related to road incidents and events. Hence, the dominant role of the road authorities and operators should be targeted whenever the crisis is actually a road network crisis, such as e.g. road closure due to flooding, avalanche or landslide.

Impact on legal frameworks

The term of "safety critical data" needs to be further defined and regulations provided accordingly to enable the secure sharing of such data in case of a road network related crisis.

3.3.3 Traffic management and control

Impact on objectives and mission

Traffic management will become 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 anticipated to most probably by 2040 become closely integrated with fleet management, at least with regard to ODD management (also with e.g. 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 NRA will with its traffic management and circulation plans set the scene and framework for all stakeholders involved.

Hence, the objectives and mission will likely be wider than today encompassing facilitating the safe operation of automated vehicles. While the problems resulting from mixed traffic of both highly automated and human-operated vehicles will result in an increased emphasis of solving these problems also with traffic management, this will not change the main mission of the road authorities and operators to ensure safe and efficient operation of the road networks. 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.

Impacts on operations and use of technologies

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), 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.

To help public authorities play the role of the orchestra conductor and translate their mobility plans into 'standardized exchangeable data', the Enhanced Traffic Management WG of the C-ITS Platform conceptualized a specific set of important tools that need to be developed for digital traffic management plans: (EC 2017)

- Classification of roads to be done accordingly to network flow hierarchy; not always the shortest path will be fastest, nor the safest.
- Geo-fencing mechanism.
- Establishing a network performance Level of Service (LoS).
- Defining triggers to engage a cooperative traffic management.

In order to make the orchestration of cooperative traffic management services possible, there is a need to develop a Common Operational Picture (COP) to provide the involved actors with a standard overview and regional context of a traffic situation. The COP can play a major role for re-routing services, e.g., for identifying the need of any additional measures or, for facilitating extra traffic on alternative routes.

The complexity to operate and maintain ITS applications has implications on budget and re-sources. 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

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

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. Traffic management of the future may also contain ODD management as one functionality.

Technically, this 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 for example 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 Electronic 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.

Impacts on NRA role

The role of NRAs 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.

Impact on legal frameworks

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.

3.3.4   Road maintenance

Impact on objectives and mission

The mission of road maintenance has always been and also will be in the future to retain certain service levels of all road infrastructure assets to ensure safe operation. While requirements and service levels are potentially highly impacted by CAD it is not expected that objectives and mission of road maintenance are affected. Road maintenance will remain an important core business field for NRAs and other road operators.

Impacts on operations and use of technologies

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 O&M works (inspections, minor repairs, winter maintenance, incident management, etc.) necessary to reach the over-arching goals will also be necessary in the future. Nowadays they are carried out by operational workers who are always at risk by carrying out their work in an environment with high-speed traffic right next to them. Supporting them 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. The good news are that such measures are not assumed to need amendments on the physical infrastructure but rather further development of the technological readiness of the systems and the according legal framework. However digital infrastructure enabling the positioning of the vehicles and according standardized, connected communication with the traffic management centre are key for the safe implementation.

Road maintenance can also benefit from new data sources on road conditions made possible through additional vehicle sensors and V2I communication. Various C-ITS projects tested and provided solutions for communication of condition data into vehicles. From a maintenance perspective the other communication direction – vehicles providing road condition data through V2I communication to the TMC – promise major improvements for predictive maintenance. Future ambitions should involve the collection of road condition data like potholes, cracks, rutting or skid resistance facilitating sensor technology of highly-automated vehicles through V2I communication. However so far it still remains unclear if CAV sensors will be suitable for the provision of condition data and how the legal barrier of providing such data can be crossed. In any case also road condition data as part of safety relevant data should be somehow made available to service and map providers to increase safety overall.

Overall the digital part of an operations management centre and the traffic management centre will need to merge and have integrated communication standards sooner rather than later. The role of the traffic management centre will become increasingly more important in an automated driving future to enable the NRAs to stay in control and to reach their policy goals.

Impacts on NRA role

The expected increasing share of digital infrastructure and the implementation of various sensors and ITS assets changes the employee structure in road maintenance. More electronics and telematics professionals will be required to carry out the routine road maintenance works which will include even more inspections and functionality tests. This shift in the employee structure could have an impact on the company culture and how work in road maintenance are perceived in the job market.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Impact on legal framework

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. While supporting automated functions are helpful in road maintenance, only driverless maintenance vehicles for safety critical tasks are able to provide the actual safety improvements for operational workers. 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 both-way data exchange on road condition legal provisions have to be made in line with general data provision and data security legislation.

Liability will potentially provide ground for legal discussions.

3.3.5   Winter maintenance

Impact on objectives and mission

The mission for winter maintenance as part of road maintenance has always been and also will be in the future to retain certain service levels of the road also in winter conditions to ensure safe operation. While requirements and service levels are potentially highly impacted by CAD it is not expected that objectives and mission of road maintenance are affected.

Impacts on operations and use of technologies

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.

In order to support snow-plough operators who are often tasked with numerous monitoring and operational activities that they need to do simultaneously while removing snow and spreading de-icing agents on the road the use of individual automated functions is tested worldwide. NRAs will have the opportunity to enrich their winter maintenance vehicle fleet with advanced driver assistance systems to ease the pressure of winter maintenance staff.

In the MANTRA Deliverable D3.2 (van der Tuin et al. 2020) simulation studies were performed with highly automated winter maintenance trucks driving at 45 km/h and 60 km/h. The results showed that the communication policies have the largest effect on smooth traffic flows. Interestingly, a "no communication" scenario where automated vehicles do not receive messages from the maintenance vehicles results on average in the most smooth traffic flows. Changing lanes directly after receiving the message of a work zone ahead resulted in a decrease of capacity on a longer stretch of road. Not only conventional vehicles were hindered in the simulation, also automated vehicles were not able to merge into the correct lane, mainly due to large speed differences between the lane where the winter maintenance vehicle was driving and the free lane. This theoretical simulation shows that communication and hence a connected approach would be beneficial providing only information to vehicles (conventional as well as automated) without a general advice. While highly automated winter maintenance vehicles are still an image of a distant future communication through C-ITS solutions can already support to 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 resulting in rerouting instead of only lane changing behaviour.

ODD requirements could shift the service levels and requirements for winter maintenance. NRAs 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.

Impacts on NRA role

This extremely safety critical maintenance task also involves a lot of manpower in rather condensed periods of time but with potentially long shifts. Seasonal workers and expensive sub-contracts are necessary and sometimes hard to find for the winter season. Driverless solutions are desirable and driven by the need to ensure safe, in this context snow- and ice-free roads, at all times. The actual NRA role is not expected to significantly change.

Impact on legal framework

Unmanned vehicles are legally not allowed on European roads except for some countries. This also includes maintenance vehicles. While supporting automated functions will be helpful in winter maintenance the long-term future goal are convoys of winter maintenance vehicles that are at least partly driverless. Amendments to legislation will be necessary to allow this.

In terms of the potential for both-way data exchange on road condition legal provisions have to be made in-line with general data provision and data security legislation.

NRAs will need to be prepared for discussion around ODD requirements in winter conditions and the respective liability for it. If NRAs 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.

3.3.6   Traffic information provision

Impact on objectives and mission

The role of traffic information is changing with the emergence of CAVs. During the last decades policy has relied on providing information on traffic conditions and problems on the road network to the driver and let the driver make the decisions based on. In order for traffic management to optimise transport system performance at all times for mitigating emissions, congestion and road fatalities, traffic managers likely need to make decisions on behalf of the individual drivers and automated vehicles.

Highly automated driving will be less dependent on the "traditional" traffic information than human drivers or travellers. However, highly automated vehicles can collect and transfer traffic and road condition related data to traffic management centres and also to other road users.

Of course, as long as there is mixed traffic on our roads (roads shared between human operated, highly automated and all in-between type of vehicles) it is out most important to ensure that everyone receives the needed traffic information with the means available to them. This may require different means for automated vehicles than for human operated vehicles.

Impacts on operations and use of technologies

Highly automated vehicles need to be aware of everything happening on the route ahead, also beyond their own sensors. Here CAVs 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.

In addition, the role of highly automated vehicles may also be in data collection, and hence have impact on operations and use of technologies.

In the future, the road users (drivers, automated vehicles, vulnerable road users) will receive information via their on-board devices in addition to roadside variable and dynamic message signs. The first mentioned can be devices embedded in the vehicle by the OEMs or aftermarket, or even 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 life-cycle, 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.

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 yet.

Impacts on NRA role

At least for now, NRA has still a role to ensure that the most critical information is shared with all the road users needing the information, no matter if automated or human driven vehicles, Moreover, if the data needed for information provision is collected more and more with the moving vehicles, someone (NRA?) is needed to process the data. Especially, if the vehicle manufacturers' fleets are only communicating among the same brand - which is one of the potential future scenarios.

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)

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Impact on legal frameworks

While data sharing can be accomplished based on voluntary cooperation, specific mandating to share vehicle-based safety-related data is likely required. Traffic information is the key commodity for the business of especially some service providers. Such mandating could be carried out as updates of the current delegated regulations on safety-related traffic information SRTI (EC 2013) and real-time traffic information RTTI (EC 2015). These updates could also specify the minimum quality requirements for such data. Mandating key pictograms for road safety related warnings could be needed.

3.3.7 Enforcement

Impact on objectives and mission

The mission and objectives of enforcement as such are not expected to change that much due to CAVs. Overall, enforcement's role is and will be on ensuring that all traffic participants are obeying the rules, to facilitate safe, fluent and predictable move of people and goods in the transport system.

Impacts on operations and use of technologies

Enforcement is a broad field including enforcement of traffic regulations, weight/dimensions restrictions, environmental rules, road user charges, etc. The whole area of enforcement will be heavily affected by not only CAVs but also digitization and connectivity in close relation with changes in traffic management. Besides the opportunities of improved cross-border and cross-entity cooperation provided by these developments, some infrastructural amendments will also be necessary to support these opportunities.

Focusing on infrastructure related consequences relevant for NRAs one particularly critical area identified in the expert workshop (Vienna, 10.09.2019) was the enforcement of allowed weights (and dimensions). With the potential of automated high capacity vehicles and truck platoons increasing loads on pavement and bridges an effective mean of weight enforcement becomes more critical than ever. The integration of weigh-in-motion (WIM) systems in the pavements and bridges with legally accurate measurements will allow for continuous measurements with less necessary infrastructural and personnel resources that are now required in designated weight control parking areas. Dimensions can be checked already now visually through toll cameras but legally those are not accurate enough as are the WIM systems.

The information exchange possible through V2I communication and connected traffic management would also provide for the potential of direct enforcement through the necessity of data provision from vehicles on their speed, weight, environmental category, etc. While this would potentially be desirable for NRAs and police, this subject is very sensitive in terms of privacy, data security and also market competitiveness. Trust building for safety critical traffic management will be more important than the outlook for an automated enforcement system in the near future.

The potential for forced vehicle stops or U-turns in case of violations such as wrong-way driving through connectivity also provides new opportunities in the future which need to be integrated in digital and physical infrastructure standards.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Impacts on NRA role & Impact on legal frameworks

The responsibility for the various types of enforcement (traffic regulations, weight, environmental, road user charges, etc.) are shared between NRAs, police and different public entities dependent on the road type (urban, motorway, etc.) and the enforcement type. Each EU country has its own slightly different split of responsibilities, so only general guidelines can be given. There will be a need to ensure, in the vehicle approval process for an ADS, that the system is capable of providing compliance with all relevant rules — speed limits, lane restrictions, access restrictions (including by time of day) and weight restrictions. This implies that an ADS will have to be aware of the gross vehicle weight and of axle load rules.

3.3.8   Road user charging

Impact on objectives and mission

Road use charges are mainly applied for financing, environmental or congestion mitigation reasons. No major change is foreseen due to the introduction of highly automated vehicles. However, road use charges can to a certain extent and for limited period of time in the initial phase be used as a tool for promoting the introduction and use of highly automated vehicles.

Impacts on operations and use of technologies

There are still many tolling technologies in use in Europe from manual payment, card payment, microwave DSRC based payment (from mono lane with barriers to free flow multi-lane) to GNSS based solutions with or without virtual toll plazas.

In GNSS based systems there exist only virtual toll plazas, if any. Consequently, properly equipped automated vehicles can behave as traditional vehicles in these systems (e.g. German and Belgian heavy goods vehicle charging systems).

Modern DSRC tolling systems are based the "multi-lane free-flow" principle. In these systems properly equipped automated vehicles can also behave as traditional ones.

Due to need to minimise vehicle kilometres travelled, and to promote ride sharing, it is possible that the road use charges in the future could also depend on the occupancy of the vehicle. This has analogy with the treatment of heavy-occupancy vehicles already today. The higher the number of occupants, the lower the price would be. Driverless vehicles without passengers would pay the highest fee.

Highly automated vehicles (possibly without a driver) requires automated payment of road use charges. This means that toll plazas need to have at least one lane for automated payment, to which highly automated vehicles are guided. An automated vehicle needs thus to have a user account, that is debited automatically, depending on the used solution, when passing a payment station (toll plaza) or for the accumulated kilometre consumption after the trip. The pricing rules may be complicated and include e.g. as a parameter the vehicle's operation mode (highly automated … human driver). Enforcement of the payment is performed using the same local solutions as for non-automated vehicles (e.g. barriers, ANPR).

However, some physical and policy measures need to be taken to allow highly automated vehicles to use pay roads and perform the payment. Such are

- physically preparing as a minimum one lane for automatic tolling
- preparing guidance to the dedicated lane for tolling of highly automated vehicles
- define a pricing policy for highly automated vehicles
- update HD maps with tolling information

- renegotiate concession agreements regarding highly automated vehicles

EETS is based on CEN EFC standards, of which DSRC is operating on 5.8 GHz. Many new ITS and communication services are using or planning to use 5.9 GHz. At a toll plaza, where CEN DSRC is used, interference between applications using the two bandwidths must be hindered, as otherwise the revenues of the tolling system are at risk. In the case of truck platoons, it may be needed to break up the platoon before passing the tolling point, if no other solution is developed.

Impacts on NRA role

No major change in the role of NRAs (or concessionaires) is foreseen.

Impact on legal frameworks

Regarding road use charges, the introduction of highly automated vehicles on tolled infrastructures requires the following legal measures:

- a pricing policy needs to be developed, possibly on a European level, as road use charges in Europe are ruled by e.g. the EETS Directive (2019/520) and the Acts given based on the Directive; the policy may include special tariffs for highly automated vehicles; also new types of vehicle classes like truck platoons are to be considered
- in the case of concession-based toll roads, it is likely that some changes in the long-term contracts need to be negotiated

3.4 Planning, building, heavy maintenance

3.4.1 New roads planning and building

Impact on objectives and mission

Objectives for planning and building of new roads in the light of the broad developments of CAD will be even more demand-driven in the future. This time not meaning the demand driven only by quantity of vehicles but rather demand defined through the various use cases of highly automated driving. The options for road usage will be broader and more diverse in the future. Therefore NRAs will need to consider factors like very variable use of roads on the one hand, like e.g. shared use of roads between different traffic modes or differentiating use at different time slots and on the other hand dedicated lanes for specific use cases, like e.g. platooning on important freight routes.

A very important side effect for the objectives and mission for new roads planning in the future and already today is the environmental impact. Feasibility and sustainability are critical more than ever for the decision-making process around the construction of new roads.

Impacts on operations and use of technologies

It is crucial that the planning of new roads obviously needs to consider and make provisions for mixed traffic and CAD. These new roads however will only be a very minor network part on which CAD will be driving. Therefore, it is even more important to define standards for

rehabilitation and extensions of existing roads considering the necessary equipment. This way road networks will be upgraded step by step as part of the continual maintenance program.

Infrastructure support levels (ISAD) as developed in the project Inframix (Carreras et al. 2018) should be further defined to provide very clear guidelines for necessary digital and physical infrastructure alike. The ISAD levels are meant to describe road or highway sections rather than whole road networks. In order to structure the various means of support that infrastructure can provide towards automated vehicles, 5 levels are proposed which are based on the idea of the SAE levels for vehicle capabilities. It is important to put both pillars into the picture, ISAD and ODD requirements, to consider their interplay and mutual dependencies. New road planning in the future needs to involve the assessment of the new sections and dependent on their importance and segment a categorization in those ISAD level. The first pillar of new requirements for new road planning should result from those ISAD level requirements.

The second pillar results from the ODD requirements as described in this report. Dependent on the respective NRAs strategy and willingness to support and widen the ODDs of different use cases, these ODD requirements should be built into the design guidelines for new roads planning. Both ISAD level requirements and ODD requirements should be applied equally not only for new roads planning but also for rehabilitations.

As described earlier prioritization in terms of road types and relevant routes are crucial based on what NRAs can afford to do. However, new road construction makes the integration of digital infrastructure much easier compared to upgrades during rehabilitations of existing roads. NRAs are advised to use this opportunity and plan the digital infrastructure requirements de-fined as part of the ISAD levels as well as the ODD requirements.

Design guidelines considering all this will need to be developed for planning of new roads as well as for upgrades of existing ones. Some countries already started to develop such guide-lines for infrastructure (e.g. U.S. DOT 2018b; Zencic 2019) but also admit that it is an ongoing approach also facing the challenges of limited, concrete exchange with CAD developers in terms of ODDs.

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. Design guidelines should therefore provide indications in which areas, road types, use cases and/or traffic volumes this could be a recommended solution.

Relevant for new roads planning will also be the shift of needs for stationary traffic. While needs for parking spaces will decrease over time, additional areas for deliveries of all kinds and sizes will increase. What bus stops are nowadays will need to be multi modal switching hubs in the future providing variable room for traffic mode switches. Some highly automated driving use cases such as automated shuttles and robotaxis require specific passenger pick-up and drop-off points.

One element of new road planning and construction is the application of the BIM (building in-formation modelling) methodology to ensure the parallel development of a so called digital twin of the new road that includes all necessary design, material and operational data for each asset. This will also provide the basis for NRA's information exchange and provisions for HD maps.

Impacts on NRA role

New road planning and building will also in the future be the sovereign duty of NRAs. Highly automated driving is therefore not expected to affect the role of NRAs in new roads planning and building.

Impact on legal framework

The manifold European and local technical standards for road planning will need to undergo continuous assessments and updates in the coming years to make the according provisions for mixed traffic and CAD.

3.4.2 Road works management and planning

Impact on objectives and mission

Highly automated driving is not expected to affect the objectives nor mission of road works management and planning.

Impacts on operations and use of technologies

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 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 mostly be equipped with hybrid C-ITS communications by 2040 and even before. 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.

Impacts on NRA role

Highly automated driving is not expected to affect the role of NRAs in roadworks management and planning.

Impact on legal frameworks

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.

3.4.3 Heavy maintenance planning

Impact on objectives and mission

Heavy maintenance planning nowadays is based on sophisticated asset management programs and deterioration monitoring. Besides the objective of preventive and cost effective heavy maintenance planning also environmental and sustainability aspects have become important in the recent past. Advanced data collection options through automated and connected vehicles on road condition can support this mission towards even more exact and hence sustainable heavy maintenance planning. With road networks in most European countries already (nearly) fully developed heavy maintenance planning is one of the biggest monetary business fields of NRAs. Importance will only increase through new or additional requirements to asset condition through highly automated vehicles ODD requirements.

Impacts on operations and use of technologies

Heavy maintenance planning can also benefit from new condition data sources made possible through additional vehicle sensors and V2I communication. Various C-ITS projects tested and provided solutions for communication of condition data into vehicles. From a maintenance perspective the other communication direction – vehicles providing road condition data through V2I communication to the TMC – promise major improvements for predictive maintenance. Future ambitions should involve the collection of road condition data like cracks, rutting or skid resistance facilitating sensor technology of highly-automated vehicles through V2I communication. However so far it still remains unclear if CAV sensors will be suitable for the provision of condition data and how the legal barrier of providing such data can be crossed. In any case also road condition data as part of safety relevant data should be somehow made available to service and map providers to increase safety overall.

Impacts on NRA role

Potentially heavy maintenance planning in the future will not solely done with NRA owned data and information but also facilitating road condition data collected by automated and connected vehicles. Therefore cooperation with data providers will be necessary. Other than that highly automated driving is not expected to affect the role of NRAs in heavy maintenance planning.

Impact on legal framework

The manifold European and local technical standards for road planning will need to undergo continuous assessments and updates in the coming years to make the according provisions for mixed traffic and CAD.

3.5 New business

Impact on objectives and mission

The objectives of the national road authorities will evolve in time due to the developments in the society. As a general trend, public sector budgets are under pressure in Europe, including those of national road authorities resulting in the need to increase the productivity of the core business areas. This will likely result also in specific objectives regarding productivity.

Impacts on operations and use of technologies

The technologies, digital infrastructure, and back-office systems for highly automated driving may facilitate and/or support several kinds of new business areas and operations. These could include:

- Provision of elements in a broader mobility-as-a-service ecosystem. Here mobility and quality of life could be blended in a technology solution where travel time and road based transport are not seen as mainly unproductive time between two destinations. This could also involve proactive management of customer expectations and societal expectations in road transport.

- Integration of a potentially increasing number of services and non-traditional vehicle concepts and services.

- Mitigation of issues of a highly fragmented communication network reality in Europe. Examples of fragmentation include end of network, end of high-quality communication infra-structure, cross-border delays and expectation management.

- Validation of service quality in communication infrastructure and digital map infrastructure

- Management of ODDs for highly automated vehicles. This could be especially important for new types of vehicles in terms of length and behaviour with various types of fleet operators and managers.

- Increasingly dynamic parking management with adaptive solutions for different types of vehicles with regard to various needs and durations of parking, including mandatory resting for professional drivers, end of ODD, building up or disconnecting platoons, robotaxis in low demand periods, etc.

Impacts on NRA role

There will likely be a more service provider oriented business model for national road authorities. The service ecosystem will likely extend and grow with much more interaction between market players and higher investments. In order to secure the investments, a licence based business model might be an option at least for some period of time as has been done in the tolling and telecommunications businesses.

Impact on legal frameworks

The role changes may need to be accompanied in national laws.

4 Road map for core business adaptation

The tables below describe the road map for the adaptation of the core business areas of the national road authorities up to 2040. The road map focuses on actions commenced already in the first five years of the period as these can now be forecasted with some certainty. The roadmap tables represented the input to a CEDR workshop held in March 2020, were validated at the workshop and are now included as "raw output" from the workshop.

4.1 Physical Road infrastructure

Table 1 contains the roadmap for physical infrastructure. While there are more than 10 action areas, some are deemed more important than the others. The challenge of increased road rutting due to lane centering of the vehicles foreseen needs to be addressed, and the best way to do this would be to have the vehicles utilise the whole lane width to achieve uniform wear of the pavement. The management of bridge loads and enhancement of the bridge loading models are another key action for the road authorities to mitigate the impacts of automated driving. The specification of the minimum risk manoeuvres is a key issue for the road authorities and operators in the future affecting not only the safety but the efficiency of the road transport system. The needs for and quality of road markings, signs, equipment and furniture are a further area of importance.

Table 1. Possible actions for physical road infrastructure

Action	2021-25	2026-30	2031-40
Uniform wear of pavement enabled by wheel path alteration in cross-section	Research on methods to alter horizontal lane positioning to ensure even wheel path distribution across lane; Research on safety aspects of "asymmetric driving"	Piloting; Negotiations, agreements with OEMs and ADS providers; Possible mandating	Take-up in all new highly automated vehicles
Pavement design and maintenance standards review and adaption (in case of failure of action above)	Studies are required to analyze rutting and fatigue potential in case of increasing unification of wheel paths. Empirical data collection on pilot project routes for truck platooning as a basis for pavement design and maintenance amendments	Pavement enforcements and increased maintenance budgets for routes with truck platooning, HCVs or car platooning with studs (Nordic countries)	Design and maintenance guidelines based on empirical data.
Pavement monitoring and maintenance on truck platooning routes (depends on actions above)	Additional pavement maintenance provisions for truck platooning routes	Strengthening of pavements on truck platooning routes as part of necessary rehabilitations; Start with core network corridors	Strengthening of pavements on truck platooning routes as part of necessary rehabilitations

Action	2021-25	2026-30	2031-40
Management of bridge loads	Inventory of (critical) bridges, their bearing capacity and condition; Inventory of bridge load models	Research and studies on the effects of e.g. platoons on bridges; adaptation of bridge load models and related guidelines	Take-up and use of models and guidelines; Deployment of a) reinforcement/ building; b) bans of platoons, c) rerouting
Additional emergency bays, wide shoulders and safe harbours	Provision of safe harbours in pilot projects and evaluation of necessity. Safe refuges or shoulder areas similar to bus stops but long enough for freight vehicles with trailers every e.g. 500m on pilot sides.	Safe refuges or shoulder areas similar to bus stops in case of narrow shoulders at intervals identified during pilots and ahead of tunnels.	Safe refuges or shoulder areas similar to bus stops in case of narrow shoulders at intervals identified during pilots and ahead of tunnels.
Safe minimum risk manoeuvre specification considering also cases of very large AV fleets	Sharing of operational practices; Agreement with OEMs, ADS providers, NRAs and other road operators; Pilots and their evaluation	Establishment of cross-sector practices; Standardisation (if sufficient maturity); Take-up in development	Roll-out and use
Safe passenger pick-up and drop-off + EV charging points for automated shuttles and robot taxis	Piloting of different solutions for different road environments (urban areas, highways, rural roads). Design specifications for passenger pick-up and drop-off points	Deployment in areas with relevant use cases (e.g. robot taxis, automated shuttles)	Deployment in areas with relevant use cases (e.g. robot taxis, automated shuttles)
General road design	New definitions in terms of visibility distance, inclinations, etc. to be defined based on findings in pilot projects.	Upgrade and amendment of general road design based on new standards during regular rehabilitation works.	Upgrade and amendment of general road design based on new standards during regular rehabilitation works.
Ramps and junctions	Identify potential problems; Initiate research and pilots. Use cases not to be expected on ramps already. Determine strategy for merging traffic for both AVs and mixed traffic; e.g. platoons and entry ramps; digital ramp control or cooperative merging	Necessary provision for lengthening and straightening ramps. Ensuring visibility and long enough weaving sections for CAD and conventional vehicles. Dedicated ramps and even junctions; Buffer arrangements for ramp control	Ensuring visibility and long enough weaving sections for CAD.

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

MANTRA

Action	2021-25	2026-30	2031-40
Road markings of sufficient retro-reflectivity in different visibility and weather conditions	Definition of specifications or even standards for machine-readability to be regularly reviewed due to AV technology evolution; Pilot project sites with various types of road marking quality to increase knowledge. Enhanced maintenance and quality management on selected roads to ensure consistent and minimum quality of solid or dotted lines and symbols painted on the pavement; Research on virtual road markings	Mix of physical and digital information on road marking for which a clear rule set in case of discrepancies needs to be defined. Development and take-up of virtual road markings	Mainly digital road guiding information, however road marking will still be required. Deployment of virtual road markings
Road signs machine readability and digital twins	Implementation of TN-ITS standards to ensure digital replications of road signs. Permanent and temporary regulatory and traffic management signs in machine-readable quality to be implemented.	Ongoing deployment and maintenance of machine readable signs.	Potentially only temporary regulatory and traffic management signs in machine-readable quality, rest already provided digitally through V2I communication.
Road equipment (gantries, gates, landmarks etc.)	Gates for separated lanes/areas to be installed on pilot project routes and crucial routes. Piloting of landmarks of different types on selected routes (incl. tunnels, fields, forests); Avoidance of new gantries	Potentially slowly decreasing need for road equipment due to digital support. To be monitored on an ongoing basis. Coverage of selected routes with landmarks for positioning support	Potentially slowly decreasing need for road equipment due to digital support. To be monitored on an ongoing basis. Full coverage of main roads with landmarks

4.2 Digital road infrastructure and ITS systems

Table 2 contains the roadmap for digital road infrastructure. The most important actions in this area relate digital twins and HD map processes – both co-dependent on large-scale roadmapping and harmonization activities in various corners in the world. Somehow through digital technologies NRAs will face opportunities and challenges in today's coping strategies with errors and risks. Shorter innovation cycles and rather high probabilities for errors in digital maps need to be addressed in potentially new operational strategies. Cooperation with OEMs and service providers will be one option to mitigate risks and to make full use of digital infrastructure's potential for effective and efficient operation in a transition period towards highly automated driving. Access to digitally excellent human resources will most probably turn out to become a key element in the future transition period. Thinking in digital ecosystems beyond traditional buyer – supplier relationships might become one necessity in coping with this dynamically evolving digital technological field.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

Table 2. Possible actions for digital infrastructure

Action	2021-25	2026-30	2031-40
HD map processes	Closely monitor process and achievements in Japan's roadmapping activity on HD maps. Agreement of the processes; Specification and setting up of NAPs	Deployment and use of the processes	In use
Provision of data to HD maps	Data from existing digital road maps of the road operators made available to service providers including map providers	Digitalisation of the TEN-T road network in required content and quality, including landmarks for positioning support	Digitalisation of all public road networks
Maintenance of HD maps	Pilots on continuous update based on feedback from sensing systems in CAVs; Investigate options to keep maintenance effort of HD maps within reasonable range	Deployment of updating process. Investigate options to keep maintenance effort of HD maps within reasonable range	In use
Accountability in case of mistakes or conflicting interpretation (mistakes will occur)	Pilots to investigate new role models (option to cover risks from a commercial cost/benefit perspective)	Explore new roles: in cooperation with OEMs and commercial automated services providers	Extend on cooperation with OEMs and commercial automated services providers
Use digital technologies to leverage "shades of knowledge" / less documented yet emerging knowledge in NRAs	Pilots to investigate	Deploy digital infrastructure to leverage emerging knowledge faster / almost near to automated detection	Deploy and exchange lessons learnt and procedures internationally
Use digital technologies to dynamically identify yet emerging new frontiers / unknown unknowns	Cooperation with ecosystem partners in machine learning and AI	Pilots	Deploy and exchange lessons learnt and procedures internationally
Cybersecurity issues	Explore risk mitigation in cooperation with other AV-related stakeholders	Explore risk mitigation in cooperation with other AV-related stakeholders	Explore risk mitigation in cooperation with other AV-related stakeholders

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

MANTRA

Action	2021-25	2026-30	2031-40
Find ways to cope with innovation risks (shorter innovation cycles in digital) (possibly in a commercial role model)	Explore new roles in buying / procurement with shortening innovation cycles as opportunities not as challenge	Explore new roles in buying / procurement with shortening innovation cycles as opportunities not as challenge	Explore new roles in buying / procurement with shortening innovation cycles as opportunities not as challenge
Rephrase procurement policies (shorter innovation cycles) accepting that there are several technology options with unclear outcome / significant investment risk	Experiment with adjusting procurement: TRL-based procurement potentially underestimates dynamically evolving digital infrastructure ecosystem	Experiment with adjusting procurement: TRL-based procurement potentially underestimates dynamically evolving digital infrastructure ecosystem	Share lessons learnt and deploy procurement strategies. Continue to adapt to shorter innovation cycles
Rephrase procurement policies towards European digital platform-based ecosystems rather than stand-alone products and services	Economic stimulation money (after Corona) could be used forward-looking into strengthening European ecosystems in AV / digital infrastructure	Evaluate lessons learnt and adapt to new ecosystem-related strengths.	Evaluate lessons learnt and adapt to new ecosystem-related strengths.
RTK or corresponding land stations	Deployment along selected roads	Deployment along TEN-T core corridors	Deployment along TEN-T networks
Provisions in tunnels	Awareness, research; pilots; Satellite positioning support, connectivity	Geofencing for hazardous goods transport; provisions for two-way traffic during maintenance	Deployments starting with critical tunnels and those on TEN-T
Trunk communications for short range and longer range V2I	Deployment on selected corridors and all new main roads	Deployment along core TEN-T corridors	Deployment along TEN-T networks
Roadside stations for short range V2I	Deployment on selected corridors and hot spots to convey critical information to AVs (e.g. related to ODD)	Deployment in hot spots and sections along core TEN-T	Deployment in hot spots and sections along TEN-T roads
External indication of being driven by ADS, or being last in platoon to ensure safety & TM	R&I to identify best solution; pilots with evaluation; drafting of specifications	Standardisation; Mandation	Take-up and use
Road operator fleet supervision centres	Research and limited pilots	Deployment and use for relevant vehicles	Deployment and use for relevant vehicles
Remote operation centres including questions of "roaming" / cooperation between operation centres	Preparation of legal framework and piloting of some operation	Deployment	In use

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Action	2021-25	2026-30	2031-40
Use of digital twins for the (road) transport system	Integration of key auto-mation concepts ODD, ISAD and information provision tools (HD Map) under the umbrella concept of the Digital Twin for the road transport system, prototypes demonstra-ting the viability, pilots starting (1)	Piloting at larger scale, operating models ready for deployment	Deployment and use, incl. adaptation
New role from digital twins spin-off

Not only for build and maintain but explicitly for high intensity simulation and traffic flow operation | Pilots of digital twins; Development and piloting of related real-time simulation models for high intensity use | Piloting at larger scale, operating models ready for deployment | Deployment and use, incl. adaptation |
Mandate to provide existing data to HD Maps	Preparation and adoption	Deployment	In use
Mandate for fleet managers and OEMs to provide feedback on HD maps	Discussion and preparation	Adoption	Deployment and use
Strengthen absorptive capacity towards arti-ficial intelligence, digi-talisation and auto-mated decision making (might involve a wide role for NRAs)	Build and contribute to a highly innovative, local digital infrastructure ecosystem	Ongoing process in a highly dynamic environment with entirely new stakeholders	Ongoing process in a highly dynamic environment with entirely new stakeholders
Human resources in digital expertise	Proactively attract digital expertise and promote challenges and opportunities	Proactively attract digital expertise and promote challenges and opportunities	Proactively attract digital expertise and promote challenges and opportunities
Competitive awareness and potential selective cooperation with big tech companies who have already taken steps into the mobility domain and increase their roles in the digital mobility ecosystem,	NRA's role in network operation and traffic management requires that NRAs are active in the digital mobility ecosystem and proactively maintain their coordinating and supervisory role in their domains.	Ongoing process in a highly dynamic environment with entirely new stakeholders	Ongoing process in a highly dynamic environment with entirely new stakeholders
Product liability issues for digital infrastructure	Research, studies, preparation in pilot contexts	Solutions case by case by front runners	Solutions case by case, based on earlier ones

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

4.3 Operations and services

Tables 3-8 contain the roadmaps for the different areas within operations and services of the national road authorities.

In order to have the impact of automated vehicles and related operations and services it is essential that the public accepts and is convinced of the use of highly automated vehicles. Hence, actions are also needed to accomplish this on a general level.

With rising proportions of highly automated vehicle, the nature of incidents and other critical events in traffic could change. Hence, research actions should monitor whether this is the case.

Incident, event, and crisis management

The most important action in this area relates to the need to clarify the champion or conductor or coordinator of incident and crisis management as well as traffic management in general. The road operators with their responsibility of the safety and efficiency of the road transport system are a natural candidate for such a role, and this should be also clarified in the legal sense with regard to road transport in Europe.

Table 3. Possible actions for Incident, event and crisis management

Action	2021-25	2026-30	2031-40
Harmonised marking of incident sites	Studies, standardisation	Profiling of the standards on the EU level, deployment	Deployment and use
Harmonised management of incident sites	Fine-tuning of processes, proposal for harmonisation	Deployment pilots for harmonised management	Deployment and use
AVs will detect and provide information on incidents, e.g. by detecting stop-ped vehicles and roadway defects	Standardisation and proof of concept. Use of hybrid C-ITS messaging	Deployment pilots	Use
Digitalisation of incident and traffic management plans	Deployment, incl. traffic circulation and traffic mgmt. plans	In use	In use
Automation of incident warning and rerouting services, e.g. for over-wide vehicles	Studies and pilots; deployment on lower automation level	Deployments and use in „easy" parts of the network	Deployment and use in main road networks
Response to emergency vehicles	Studies and standardisation (needs V2V and V2I)	Pilots; Deployment	Deployment and use
Use of safety trailers at incident sites to safeguard clearance	Studies and pilots	Deployment and use in selected parts of the network	Deployment and use in main road networks
Use of safety trailers and similar to protect moving events	Pilots and early deployment	Deployment and use	

Action	2021-25	2026-30	2031-40
Provision incident and event mgmt related data to traffic managers and service providers	Studies, agreements and MoUs, pilot deployment	Mandation on the EU level	Deployment and use
Prediction of incidents via AI	Research, pilots, development of business model	Deployment and use on selected networks by front-runners	Deployment and use
Legal adaptations to enable data sharing of safety critical data	Further definitions and harmonization	Use	Use
Leading or coordi-nating role of NRAs & ROs in road incident management	Studies, piloting including by CEDR	National fore-runners	Mandation on the EU level

Traffic management and control

In traffic management, some priority actions are essential for connected and highly automated driving. The digitalisation of traffic rules and regulations should be accomplished in a harmonised and secure manner. The use of geofencing for traffic and ODD management is becoming an important work item for the road authorities and operators. With regard to innovative solutions, the concept of real-time lane management should be studied for eventual take-up and deployment.,

Table 4. Possible actions for traffic management and control

Action	2021-25	2026-30	2031-40
Cooperative traffic management concept	Studies and pilots	Deployments in key peri-urban areas by forerunners	Deployment and use
Digitalisation of traffic management centres	Deployment, including traffic circulation and traffic management plans	In use	In use
Access control (slots) and/or pricing	Research on feasibility and pilots on relevant networks	Deployments in key peri-urban areas by forerunners	Deployment and use

MANTRA

Action	2021-25	2026-30	2031-40
Digitalise traffic rules and regulations	Studies, pilots, standardisation (but question is who does the standardisation)	Deployment; development & standardisation of Trusted Electronic Regulations Access Points (TERAP)	In use; deployment of secure TDRAPs
Deployment of geofencing for traffic management	Research, pilots for different orientation (safety, emissions, AVs, Non-AVs…); Deployment by forerunners	Harmonised specifications for TM related geofencing; Deployment in key peri-urban areas	Deployment and use; continuous adaptation of specifications
Provision of ODD management	Research, agreements and MoUs with OEMs and ADS providers	Studies, pilots, standardisation	Deployment and use, continuous adaptation with ODD evolution
Conductor role of road authority/ operator in traffic management (see incident management)	studies, pilots, deployment by forerunners Maybe EU Mandate No. 3.4 of the Work Programme 2018-2022 of the ITS Directive, i.e. to look into data from vehicles to be shared for purposes of traffic management. Support study EC has been launched and will be finalised end 2020. Delegated Regulation prep to be expected subsequently	EU level mandate of complying to traffic management and circulation plans, and to share data for traffic management No. 3.4 of the ITS Directive is relevant	Mandate to comply to TDRAP
Real-time lane management	Research on principles and possibilities; pilots	If feasible, demonstration projects, take-up, use	If feasible, take-up and use
Removal of informative and route guidance road signs – relevant for all vehicles	Research on distraction impacts; inventory of road signs to be potentially removed; Plan for removal in stages	Phase-in of removal plan	Adaptation and deployment of removal plan

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Action	2021-25	2026-30	2031-40
Flexible roadside stations	Piloting and specifications for flexible roadside stations	Replacement of existing limited purpose stations with flexible ones	Replacement of existing limited purpose stations with flexible ones
Use of digital twins for the (road) transport system	Integration of key automation concepts (ODD, ISAD) and information provision tools (HD Map) under the umbrella concept of the Digital Twin for the road transport system, prototypes demonstrating the viability, pilots starting (1)	Piloting at larger scale, operating models ready for deployment	Deployment and use, incl. adaptation
New role from digital twins spin-off Not only for build and maintain but explicitly for high intensity simulation and traffic flow operation	Pilots of digital twins; Development and piloting of related real-time simulation models for high intensity use	Piloting at larger scale, operating models ready for deployment	Deployment and use, incl. adaptation
issues of human decision making at traffic management centres	Prepare legal ground for automated decision making	deploy	Operate 24/7 without human involvement
New role: Traffic control room paradigm shift from safety-orientation to optional societal optimum risk management	Study options and feasibility into how new forms of evidence-based management from ubiquitous sensors and data would challenge some dominant role models	Piloting new societal optimum risk management approaches	deploy

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

MANTRA

Road and winter maintenance

This area was not addressed at the CEDR workshop of March 2020, and thereby no priority topics have been verified.

Table 5. Possible actions for road and winter maintenance

Action	2021-25	2026-30	2031-40
Integration of operations management centre and traffic management centre	Definition of data exchange and processes	Integrated processes and communication	Use
Connected road maintenance zones	Data exchange and definition of standardized processes for temporary maintenance zones	Integrated processes and communication	Use
Legal framework for specific use cases of driverless maintenance vehicles	Provision of legal framework for initial use cases like driverless safety trailers, mowing robots	Legal framework for additional use cases	Legal framework for driverless winter maintenance vehicles
Procurement of automated winter maintenance vehicles	Pilot projects and test sites for winter maintenance vehicles with advanced driver assistance systems and driverless vehicles for rest areas and other areas without fast moving traffic	Procurement of driverless winter maintenance vehicles for rest areas. Procurement of winter maintenance vehicles with advances driver assistance systems for safety critical routes	Pilot projects and potentially deployment of driverless winter maintenance vehicles for some routes.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Traffic information services

The provision of short-, medium- and long-range hybrid C-ITS communications is essential for highly automated driving, and thereby a priority.

The data provided needs to be of sufficiently high quality to ensure safe automated driving, which in turn requires efficient quality assessment and effective quality assessment procedures and processes.

Table 6. Possible actions for traffic information services

Action	2021-25	2026-30	2031-40
Standard AV-suitable comm protocols with TMC, fleet managers, service providers and automated vehicles	Development of standardized communication protocols, and use of sensors. Need of AV-specific messages?	Deployment and use by forerunners; mandation on the EU level	In use
Provision of hybrid C-ITS traffic information services	Specs & profiling of hybrid C-ITS traffic info services; large scale piloting; guidelines for use; deployment and use by forerunners	Deployment and use	In use
Enhancing traffic information content	Research on optimal, smart traffic system level optimized routing and guidance	Pilots in major cities and peri-urban networks	Deployment and use with continuous learning
Improving information quality	Development and take-up of quality assurance processes for traffic information	Deployment and use	In use
Quality assurance and assessment of data	Development of processes and techniques for the data chain	Demonstration projects; take-up and use	Take-up and use
Sharing of data and storage of data (note: also relates to Enforcement)	Agreements between stakeholders, deployment of SRTI; Define categories of incidents; Pilots (note the Data Task Force PoC (Proof of Concept)	Mandating the sharing of safety-related and traffic management related data; note current EU support study on sharing of vehicle data for traffic management.	Deployment and use
Harmonisation of pictograms and messages (including messages in text)	Discussion and hopeful agreement between stakeholders	Standardisation of pictograms for warnings and regulatory information	Possible mandation of pictograms; Deployment and use

Action	2021-25	2026-30	2031-40
Use of digital twins for the (road) transport system	Integration of key automation concepts (ODD, ISAD) and information provision tools (HD Map) under the umbrella concept of the Digital Twin for the road transport system, prototypes demonstrating the viability, pilots starting (1)	Piloting at larger scale, operating models ready for deployment	Deployment and use, incl. adaptation
Security of data (note: also relates to Enforcement)	Security and privacy of low-level data. Access to data for environmental management and enforcement	Security and privacy of low-level data. Access to data for environmental management and enforcement	Security and privacy of low-level data. Access to data for environmental management and enforcement

Enforcement

Table 7. Possible actions for enforcement

Action	2021-25	2026-30	2031-40
New infrastructure and regulations for traffic law enforcement, including for conventional vehicles	Connected speeding cameras with necessary accuracy to still needed for human operated vehicles;	Use	Use
Enforcement through weigh-in-motion systems	Tests of necessary accuracy of WIM systems; preparation of legal framework for enforcement and requirement to use WIM	Direct V2I information of truck weights	Use
Tamper prevention	Monitoring of tampering activities; Development of effective prevention and mitigation measures.	Continuing action	Continuing action
Environmental enforcement	Regulation of data exchange of environmental information of vehicles with infra for geofenced areas. Upgrade of CCTV for identification of environmental vehicle categories where necessary. Preparation of legal framework for enforcement.	Use including instruction to vehicles on power mode for local environmental management	
Wrong way and tunnel driving detection and enforcement; routing enforcement	Automated vehicles to detect the wrong way driving and share the information with predicted location to enhance safety; piloting	Extending the use to variety of networks	in Use

Road user charging

This area was not addressed at the CEDR workshop of March 2020, and thereby no priority topics have been verified.

Table 8. Possible actions for road user charging

Action	2021-25	2026-30	2031-40
Implementing of physical measures possibly required by highly automated vehicles on toll plazas	Development and agreement of physical measures	Deployment of physical measures	Use
Marking of toll plazas for highly automated vehicles	Development and agreement of standardised markings and guidance	Deployment of standardised markings and guidance	Use
Definition of a pricing policy for highly automated vehicles	Research followed by a policy definition (possibly on an European level)	Deployment and use	Use
Inclusion of road use charges into HD maps	Specifications: development and agreement concerning dynamic charging	Deployment and use	Use
Update of concession agreements	Negotiations and agreement on how the pricing policy is applied on the concession network	Deployment and use	Use

4.4 Planning, building, heavy maintenance

Tables 9-11 contain the roadmaps for the different areas within planning, building and heavy maintenance. This area was not addressed at the CEDR workshop of March 2020, and thereby no priority topics have been verified.

New roads planning and building

Table 9. Possible actions for new roads planning and building

Action	2021-25	2026-30	2031-40
Road categorization ISAD levels also for digital and physical infrastructure	Further specification and official introduction of ISAD levels for digital and physical infrastructure	Consideration of vehicle sensor evolution in further development of infrastructure specifications. Annual review of new roads design guidelines	Consideration of vehicle sensor evolution in further development of infrastructure specifications. Annual review of new roads design guidelines
Provision of digital twin and digital data of new road	BIM approach and data structure to be clearly defined and applied already in planning of all new roads planning	Use	Use

Road works management and planning

Table 10. Possible actions for road works planning and management

Action	2021-25	2026-30	2031-40
Standardized communication protocols with TMC, fleet managers, service providers and automated vehicles	Development of standardized communication protocols, work zone layouts and use of sensors.	Deployment and use by forerunners; mandation on the EU level	In use
Provision of hybrid C-ITS road works warnings	Specification and profiling of hybrid C-ITS road works warnings; pilots; guidelines for use; deployment and use by forerunners	Inclusion in road works contracts; deployment and use on selected corridors and networks	Deployment and use
Harmonised marking of road works sites	Studies, standardisation	Profiling oft he standards on the EU level, deployment	Deployment and use
Harmonised manage-ment of road works sites	Fine-tuning of processes, proposal for harmonisation	Deployment pilots for harmonised management	Deployment and use
Use of safety trailers at road works to ensure safety	Studies and pilots;	Deployment and use in selected parts of the network	Deployment and use in main road networks
Use of automated vehicles to monitor the performance of road works management	Research, studies, pilots; specification of processes; deployment by forerunners	Harmonised specification of processes; contracts with fleet managers; Deployment on selected corridors and networks	Deployment and use in main road networks

Heavy maintenance planning

Table 11. Possible actions for heavy maintenance planning.

Action	2021-25	2026-30	2031-40
Use of digital twin and digital data of new road for heavy maintenance planning	BIM approach and data structure to be clearly defined and applied already in planning of all new roads planning	Use	Use
New approaches to road condition data collection for deterioration monitoring	Pilot projects for sensors collecting road surface condition data (rutting, skid resistance, etc.) further development of algorithms for deterioration models	Use and further development	Use and further development

4.5 New business

Table 12 contains the roadmap for new core business. The core business areas of national road authorities are in most countries determined by national laws, affected by European legislation. Hence, changes in national or European legislation can result also in the need for the national road authorities to take up new business areas. It might also happen that the evolution of the mobility and transport landscape changes so that there is a need for an organisation such as a national road authority or road operator to assume a new role and task in the mobility or transport ecosystem, resulting in a new business area for the road authority/operator. In both cases, it would be fruitful to consult CEDR and other road authorities and operators, which have already looked at and perhaps even carried out such tasks.

Table 12. Possible actions for new business.

Action	2021-25	2026-30	2031-40
Adopting new business areas when necessary	Develop and adopt new business area due to changes in legal framework on the EU and national level or reorganisation on the national or regional level making it necessary to adopt a new role and/or task. The practices in other countries and regions should be considered in the process.		
Adopting new business areas when appropriate	Develop and adopt new business area due to the needs of the transport and mobility system for the national road authority to adopt a new role and/or task. The practices in other countries and regions should be considered in the process.		

4.6 Prioritization of actions

4.6.1   Priority survey

MANTRA organised a workshop in Vienna, Austria, on 13 March 2020 for CEDR members, which had the chance of discussing the actions proposed in the previous sub-chapter and the priorities of the actions. Due to the outbreak of the corona virus pandemic, most of the experts that were planning to participate in the workshop had to cancel their participation. Hence, there was a need to verify the actions and to identify the most crucial actions to be carried out. 92 actions are clearly such a high number that priorities are needed.

Hence, MANTRA organised a survey sent out on Monday 6 April to more than 160 recipients. Most of them represented European road authorities and operators, and others were experts from the EC, ministries, agencies, research, academia and consultancies cooperating with road authorities and operators in the domain of connected and automated driving. The primary purpose of the survey was to identify the priority actions among the ones selected. Additional objectives were to verify the content of the actions and even to provide proposals for actions that we have overlooked, although only two respondents provided comments concerning the contents of the action.

The deadline of the survey was 30 April 2020, leaving the respondents more than three weeks' time. The survey was organised as a web survey, and the results accessed from the web storage on 7 May 2020. In all, there were 21 respondents from national road authorities or the relevant ministries, and 24 other respondents. The survey instructions and results are shown in detail in Annex 1.

4.6.2   Results of the survey

The number of priorities were restricted to 3-5 per table, depending on the number of candidate actions. The respondents were instructed to score the priorities only to those business areas with which they were familiar, Thereby, some respondents did not give priorities in all areas. Furthermore, some respondents indicated less priorities than the maximum number for some business areas. On average, national road authority respondents gave priority nominations to more tables than other respondents.

The priority actions to be included in the action plan were selected by choosing the clearly prioritized actions from each table, giving somewhat more weight to the NRA respondents' priority nominations in case the action was not prioritized by both NRA and other respondents. At this point, actions closely related were combined in cases where one or two of these actions were close to prioritisation threshold but not above it. This procedure resulted in 22 priority actions listed in Table 13. These priority actions were included in the recommended action plan for the adaptation of NRA core business.

Table 13. Priority actions selected on the basis of survey.

Business area	Action
Physical infrastructure	Optimal minimum risk manoeuvres and providing infrastructure for them
Physical infrastructure, Digital infrastructure	Road signs' machine readability and digital twins
Physical infrastructure	Road markings of sufficient retro-reflectivity in different conditions
Digital infrastructure	Ensuring up-to-date content of HD maps
Digital infrastructure	Provision of road network related data to HD maps
Digital infrastructure, Traffic information	Cybersecurity issues for connected and highly automated vehicles
Digital infrastructure, New roads planning and building	Digital twins for road transport system including ODD and ISAD information
Digital infrastructure	Human resources with digital expertise
Incident, event, and crisis management	Information provision on incidents, events and crises
Incident, event, and crisis management	Digitalisation of incident and traffic management plans
Incident, event, and crisis management	Harmonised marking of incident sites to be correctly recognised by AVs
Traffic management and control	Cooperative traffic management concept
Traffic management and control	Digitalise traffic rules and regulations
Traffic management and control	Digitalisation of traffic management centres
Traffic information	Improved information quality for automated vehicles
Traffic information, Road works management and planning	Standard communication protocols related to automated vehicles
Traffic information	Provision of hybrid C-ITS traffic information services
Enforcement	New infrastructure and regulations for traffic law enforcement
Enforcement	Environmental enforcement utilising geofencing and other tools
New roads planning and building	General physical road design changes
Road works management and planning	Harmonised management of road works sites
Road and winter maintenance	Legal framework for driverless maintenance vehicles

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

5 Recommended action plan 2020-2024

5.1 Description of actions

The actions are oriented towards road authorities and tasks required for them to carry out or participate in. The actions are described using a common template describing the business area, the content and timeframe of the action, the automated driving task and stakeholders affected, the legal prerequisites, the responsible stakeholders and their responsibilities, the roles of CEDR and NRAs, and the possible risks.

PI1	Optimal minimum risk manoeuvres and providing infrastructure for them
Business area	Physical infrastructure
Description of action	Planning, design, piloting and provision of additional emergency bays, wide shoulders etc. to accommodate minimum risk manoeuvres (MRM) for automated vehicles. The first task is to determine the type of MRMs for various use cases and road types, and after that the likely locations and conditions when MRMs would occur. Then the optimal solutions for such safe harbours need to be developed and then tested and piloted in practice. After de-facto standardisation of the best solutions in cooperation with OEMs and ADS developers, deployments can commence.
Timeframe	2021-2023 research on suitable MRMs, their need in different road environments, and related physical infrastructure to accommodate large AV fleets on roads; piloting on test sites; participation in related standardisation activities
	2023-2025 piloting on open roads, agreement on MRMs of different use cases and operating environments between stakeholders; participation in related standardisation activities
	2026-2030 standardisation of MRMs and their physical infrastructure aspects for relevant use cases and operating environments; deployment of physical infrastructure by road authorities and operators starting with priority corridors
Aspect of CAD affected	All SAE2-4 use cases whenever leaving the ODD
Stakeholders affected	Road authorities and operators, OEMs, ADS developers and providers, the users of automated vehicles
Legal prerequisites	The basic demands for what can be accepted as a MRM should be clearly specified in law. This should make clear whether MRM can be stopping on driving lane, stopping on road shoulder, driving slowly ahead until reaching a safe stopping zone, etc. and how the operating environments affect this. Legal framework needs to be set up to enable road operators to forbid use in automated mode for vehicles with unsafe or otherwise harmful MRMs.
Responsibilities	Owner/champion: Road authorities/operators in close cooperation with OEMs. Other necessary stakeholders: ADS and Tier1 providers.
Role of CEDR/NRAs	Even though the MRM is carried out by the vehicle produced by OEMs, the MRMs are crucial for the road operators in terms of safe road and network operation especially in adverse conditions while at the same time possibly requiring costly investments. Hence, CEDR needs to discuss the issue with ACEA and agree on related cooperation, and also encourage NRAs to participate in related research, piloting, and standardisation activities. The NRAs need to participate in these activities in close cooperation in order to optimise the use of resources.

PI1	Optimal minimum risk manoeuvres and providing infrastructure for them
Risks involved	Development of MRMs without concern for safe and efficient road network operation resulting in additional congestion, crashes and high investments. Potential costly infrastructure adaptations are also a considerable financial risk.
Other relevant aspects	Governance and sharing of the ODD and MRM descriptions and specifications. In-depth studies of ODDs and potential locations and consequences of MRMs by individual NRAs on their networks would be useful.

PI2	Road signs' machine readability and digital twins
Business area	Physical infrastructure, Digital infrastructure
Description of action	The action aims to ensure road signs' visibility, machine readability and digital twins, including variable message signs (VMS), in addition to standard maintenance procedures to ensure their visibility by clearance of vegetation, snow, and other substances on the signs as well as correction of damages and malfunctions. The European and global standardisation of road signs also supports this action. The actual action contains the deployment of permanent and temporary regulatory and traffic management signs in machine-readable form and quality. A specific action is to replace such VMS, the displays of which may not always be readable by the sensors of the automated vehicle. This is due to the fact that to reach good display clarity while minimising electricity and maintenance costs and prolonging product life, the lights are pulsed from 0 to 100% with specific frequencies. Some frequencies do not match well the capabilities of the vehicle sensors, and they should be replaced with VMS with LED pulsing appropriate with regard to automated vehicle sensor capabilities. The action also contains the implementation of TN-ITS and related de-facto and regular standards to ensure digital replications of road signs in a way enabling automated vehicles to utilise the information in HD maps.
Timeframe	Continuous: when purchasing new VMS or replacing old VMS at end of lifecycle, acquire VMS with light pulsing compatible with automated vehicle sensors; carry out good sign maintenance processes
	2021-25 implement the replication of road signs as their digital twins in HD maps; participate in the work of related harmonisation and cooperation platforms (TN-ITS follow-ups)
Aspect of CAD affected	Sensing of connected and automated vehicles
Stakeholders affected	Road authorities and operators, vehicle camera providers, VMS providers, OEMs
Legal prerequisites	The legal framework exists.
Responsibilities	Owner/champion: road authorities and operators; necessary stakeholders: VMS providers, road maintenance contractors; Other stakeholders: OEMs and their device providers, research and academia
Role of CEDR/NRAs	NRAs to deploy
Risks involved	Possible change of automotive camera technology making the physical and digital infrastructure changes unnecessary – low risk.
Other relevant aspects	The cameras of the automated vehicles should be standardised in accordance with the pulsating LEDs.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

PI3	Road markings of sufficient retro-reflectivity in different conditions
Business area	Physical infrastructure
Description of action	Both human-operated and also likely highly automated vehicles need road markings of sufficient retro-reflectivity in different visibility and weather conditions. Hence, materials of sufficient retro-reflectivity need to be used when painting new or renewing road markings. At the same time, traces of old and not relevant road markings still visible need to be removed or permanently covered in order not to confuse the sensing and planning systems of automated vehicle nor the human drivers. A key action is to specify the quality of machine-readability actually needed by highly automated vehicles specifically in different road types, weather and visibility conditions. A realistic minimum standard needs to be defined, which NRAs are actually able to provide without liability issues. An additional task is to investigate the feasibility of virtual road markings, which can be produced on road surface by laser technologies and can be dynamically altered to adapt to prevailing traffic and environmental conditions. Such technologies have already been used in terminal areas and warehouses.
Timeframe	Continuous maintenance process including monitoring of marking quality as well as product development process for road marking and related material providers. 2021-2025 Definition of specifications or even standards for machine-readability to be regularly reviewed due to automated vehicle technology evolution; Piloting of various types of road markings with varying quality and in different environmental conditions to support specification actions; Enhanced maintenance and quality management on selected roads to ensure consistent and minimum quality of solid or dotted lines and symbols painted on the pavement; Research on virtual road markings. 2026-30 Mix of physical and digital information on road markings for which a clear rule set in case of discrepancies needs to be defined. Development and take-up of virtual road markings.
Aspect of CAD affected	Sensing and trajectory planning of automated vehicles
Stakeholders affected	Road authorities and operators, maintenance contractors, road marking material providers, virtual marking providers, OEMs, ADS providers, drivers and users of automated vehicles
Legal prerequisites	The legal framework exists for physical road markings but needs to be stablished for virtual ones.
Responsibilities	Owner/champion: road authorities and operators; necessary stakeholders: maintenance contractors, road marking material providers, virtual marking providers; other stakeholders: OEMs, ADS providers, research and academia
Role of CEDR/NRAs	NRAs to deploy
Risks involved	The sensor technology evolution might mean that the current retro-reflectivity standards could apply for highly automated vehicles as such. In the future, highly automated vehicles will not require road markings any more as the vehicles evolve towards full automation. Hence, at some distant future road markings may become redundant.
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

DI1	Ensuring up-to-date content of HD maps
Business area	Digital infrastructure
Description of action	It is necessary to set up processes to produce HD maps with constantly updated content. The issues are global, and it is useful to utilise the experiences and findings in other parts of the world. A cornerstone in building up and especially maintaining the up-to-date content of HD maps is to establish an efficient process for HD map related data exchange between the key stakeholders, i.e. the digital map providers, road authorities and operators, OEMs, fleet operators, and the connected and automated vehicles. The inclusion of the latter in a feedback loop is essential as they will likely be the first to detect by their sensors any anomalies between the HD map data and what is the case in real life on the road. Hence, such feedback loops need to be set up for maintaining HD map data quality. In addition, the necessary data elements for physical and digital infrastructure and other ODD related data as well as digital traffic rules have to be included, and the HD maps localization quality needs to be reached. A promising option is to utilise the data exchange concepts widely used in various business domains involving both public and private stakeholders, the International Data Spaces concept (IDSA 2020).
Timeframe	2021-2025 Closely monitor process and achievements on global, e.g. Japan's, road mapping activity and HD maps; Agreement of the processes between stakeholders; Specification and setting up of related NAPs (National Access Points); Pilots on continuous update based on feedback from sensing systems in connected and automated vehicles; Agree and start work on the standardisation needed. 2026-2030 Deployment and use of the processes; Deployment of the updating process; Enhancement of the processes to keep maintenance effort of HD maps within reasonable range in terms of personnel and financial resources.
Aspect of CAD affected	Sensing related to the positioning of the (ego) vehicle, all subtasks of the planning task
Stakeholders affected	Ministries of transport, Digital map providers, road authorities and operators, cities, fleet operators and managers, OEMs, ADS providers, drivers and users of connected and automated vehicles.
Legal prerequisites	The legal framework needs to be set in place for ensuring the data quality and security in HD maps and the liabilities involved. Regulation could be needed for the OEMs, fleet managers and other stakeholders governing the data from connected and automated vehicles to provide feedback about the anomalies in HD maps detected by their vehicle fleets.
Responsibilities	Owner/champion: Ministries of transport/European Commission; necessary stakeholders: digital map providers, road authorities and operators, cities, fleet operators and managers, OEMs, drivers and users of connected and automated vehicles., other stakeholders: -
Role of CEDR/NRAs	CEDR to safeguard the interests of NRAs in cross-sectoral discussions related to governance issues. NRAs act as active partners in maintaining the HD maps and deployment of the processes involved
Risks involved	The main risk is that the institutional issues in setting up the processes delay the deployments considerably. The governance of HD maps is a key strategic asset in a digital transport and mobility ecosystem. Road operators and the competent authorities within Member States should consider aligning their contribution to HD maps via a dedicated forum. There are also risks of too heavy HD map processes.
Other relevant aspects	

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

MANTRA

DI2	Provision of road network related data to HD maps
Business area	Digital infrastructure
Description of action	The road network data will need to be digitized including any landmarks supporting accurate vehicle positioning. This will be carried out by HD map providers, but also road authorities and road operators may want to have it done for themselves as HD maps of the roads and their (sub-)structures can be regarded as a key strategic asset of the road operators with regard to their core business. HD maps may be inaccurate and inconsistent due to various reasons. It is also possible that road operators have the potential to support automation by creating their own HD maps. This could be driven, for instance, by the need to have highly automated road building, road works, and maintenance vehicles. The road operators are expected to provide data for the HD maps to digital map and service providers directly or via national access points. The profiles, formats, structures and procedures needed to handle data streams are to be specified and tested in agreement with other stakeholders, and especially the HD map providers. Most of these processes are determined in action DI1.
Timeframe	2021-2025 Data from existing digital road maps of the road operators are to be made available to digital map and service providers 2026-2030 Digitalisation of the TEN-T road network in required content and quality, including landmarks for positioning support, and other ODD related data
Aspect of CAD affected	Sensing related to the positioning of the (ego) vehicle, all subtasks of the planning task
Stakeholders affected	Road authorities and operators, cities, digital map providers, service providers, road building and maintenance contractors, fleet operators and managers, OEMs, ADS providers, drivers and users of connected and automated vehicles.
Legal prerequisites	There is likely a need for a mandate for road operators to make their existing data available for HD road map purposes. The increasing provision of digital infrastructures to ensure the ODD for automated vehicles will likely also result in increasing number and importance of product liability issues.
Responsibilities	Owner/champion: road authorities and operators, necessary stakeholders: governors of European/national HD map access points, transport authorities, cities, digital map providers, road building and maintenance contractors, fleet operators and managers, other stakeholders: OEMs
Role of CEDR/NRAs	CEDR to safeguard the interests of NRAs in cross-sectoral discussions. NRAs carry the responsibility for deployment and its preparations
Risks involved	Outsourcing of HD maps to digital map providers will carry considerable risks as the market may not be competitive enough in the long run. The resources needed for providing the data may turn out to be higher than anticipated.
Other relevant aspects	

DI3	Cybersecurity issues for connected and highly automated vehicles
Business area	Digital infrastructure, Traffic information
Description of action	The security of data collected by vehicle computers and the protection of on-board systems against intrusion are becoming more prominent concerns. Many of the sensors and automated components providing functions now handled by the driver will generate large amounts of data about the vehicle, its location at precise moments in time, driver behaviour, and vehicle performance. The systems that allow vehicles to communicate with each other, with roadside infrastructure, and with manufacturers seeking to update software will also offer portals for possible unauthorized access to vehicle systems and the data generated by them. Protecting automated vehicles from hackers is of paramount concern to public authorities, OEMs, road operators, service providers, and vehicle users. Requirements that increasingly automated vehicles accept remote software updates, so that owners do not need to take action each time software is revised, are in part a response to concerns that security weaknesses be rectified as quickly as possible. The industry has already addressed these concerns by their cybersecurity principles and setting up clearinghouse for OEMs.

The road authorities need to set up their own cybersecurity processes and tools related to connected and automated driving, including the physical and especially digital infrastructure supporting it. This could include establishing good cybersecurity practices, improving information sharing with industry actors and exchanges with security researchers and third parties, clarifying liability among the stakeholders involved in case that security issues arise, and achieving consensus on technical standards for good cyber security practices. Testing and piloting should routinely involve also the cybersecurity dimension. |
| Timeframe | 2021-2025 Studies to identify CAD related cybersecurity issues; Testing and piloting of cybersecurity threats and solutions; Cross-sectoral agreements on solutions and responsibilities; Standardisation

2026-2030 Continuous monitoring of cybersecurity issues and testing of cybersecurity solutions; Determining of, agreeing on, and standardisation of solutions |
Aspect of CAD affected	All aspects
Stakeholders affected	Drivers and users of connected and automated vehicles, OEMs, ADS providers, road authorities and operators, cities, fleet operators and managers, service providers, telecom industry and operators, national security agencies,
Legal prerequisites	Basic prerequisites exist, but new or adapted regulations may be needed depending on the emergence of new cybersecurity issues
Responsibilities	Owner/champion: OEMs (vehicle security), road authorities and operators (road operation related security), telecom industry and operators (communications security) and national cybersecurity agencies (society/user security) necessary stakeholders: fleet operators and managers service providers, ADS providers
Role of CEDR/NRAs	CEDR to share best practices among NRAs. NRAs to deploy and manage cybersecurity of their own systems and infrastructures.
Risks involved	Risk of careless stakeholders in the processes; risk of massive cyberattacks
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

DI4	Digital twins for road transport system including ODD and ISAD information
Business area	Digital infrastructure, New roads planning and building
Description of action	The action contains the inclusion of ODD attribute related data to be used in HD digital maps. These include, for instance, physical infrastructure attributes such as facilities/spaces for carrying our minimum risk manoeuvres, existence and condition of game fences, existence and service levels of passenger pick-up/drop-off points, etc. Similar treatment is given to digital and communication infrastructure related attributes. This action also involves the attributes relevant for the ISAD levels.
	Cooperative traffic management would benefit from having a real-time digital twin of the transport system as an element of the digital infrastructure in addition to enabling ODD aware traffic management. The digital twin would make it possible 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. This calls for close cooperation of road transport system and traffic managers as well as the fleets of connected vehicles to provide a high quality real-time situational picture of the transport system. This situational picture acts as the fundament for the simulation tools.
Timeframe	2021-2025 Identification of ODD and ISAD related attributes in dialogue between OEMs and road authorities and operators; research and studies on ODD and ISAD related attributes and their key values; ODD and ISAD related standardisation; Development of real-time digital twin including traffic flows; R&I to provide proof of concept and pilot the solutions,
	2026-2030 Deployment of digital twins with ODD and ISAD information as well as real-time traffic flows; Adaptation of ODD and ISAD attributes along with the evolution of ODDs and emergence of new use cases;
Aspect of CAD affected	Planning of routes, minimum risk manoeuvres
Stakeholders affected	Road authorities and operators, cities, traffic management operators, fleet operators and managers, digital map providers, service providers, telecom industry and operators, OEMs, ADS providers, drivers and users of connected and automated vehicles
Legal prerequisites	Regulation is likely needed to mandate the OEMs to provide detailed information of the ODDs of their vehicles to the managers and operators of the physical, digital and communication infrastructures. Physical, digital and communication infrastructure managers and operators are likely regulated to provide their ISAD level information fo OEMs and fleet operators and managers,
Responsibilities	Owner/champion: Road authorities and operators, cities (ODD and ISAD attributes) and traffic managers (digital twin with traffic flows; necessary stakeholders: OEMs, digital map providers, service providers, telecom industry and operators, fleet operators and managers; other stakeholders: ADS providers, drivers and users of connected and automated vehicles
Role of CEDR/NRAs	CEDR to carry out cross-sectoral discussions with key stakeholders to reach agreement on solution. NRAs to deploy, manage and operate in practice.
Risks involved	Technological diversity of automated vehicle solutions provides much complexity and delays the solutions. A digital twin with traffic flows might carry too high costs.
Other relevant aspects	The MRMs are also relevant here. For instance, if a vehicle cannot guarantee that it can safely pass a work zone or bridge without resorting to an unsafe MRM, it might result in the request to leave the road before entering the sensitive area.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

DI5	Human resources with digital expertise
Business area	Digital infrastructure
Description of action	Digitalisation of the transport system and the core business of road authorities and operators means that there must be sufficient digital expertise in NRA organisation and processes. Expertise on digitalisation, big data and data analytics, digital communication systems, artificial intelligence, automation, and all aspects of digital infrastructure should be available. Some of the expertise can naturally be purchased by contracting projects and activities to service providers, but even contracting itself needs expertise also on the NRA side. However, the digitalised processes in core business will require high quality in-house expertise as well.
	The action requires that training and education will be provided to NRA personnel while at the same time opportunities to learning by doing should be promoted and encouraged in all projects developing and deploying digital infrastructure and related processes. Close cooperation with and active participation in national and international platforms related to digital transport systems and infrastructure will provide excellent opportunities for building up expertise in the domain. At the same time, digital expertise should be used as one of the criteria in recruiting new personnel. Universities should be encouraged to include transport as one of the application areas in their courses related to digital technologies and infrastructure.
Timeframe	2021- Proactively attract digital expertise; Promote challenges and opportunities to accumulate expertise and experience in "learning by doing"; Active participation in relevant national and international platforms and key projects for learning purposes.
Aspect of CAD affected	All aspects related to digital infrastructure
Stakeholders affected	Road authorities and operators, service providers, contractors, academia
Legal prerequisites	The legal framework is in place.
Responsibilities	Owner/champion: road authorities and operators, necessary stakeholders: service providers, academia, other stakeholders
Role of CEDR/NRAs	CEDR to share and facilitate development of best practice. NRAs to accumulate their digital expertise.
Risks involved	Reliance on service providers and big tech companies resulting in additional costs
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

IM1	Information provision on incidents, events and crises
Business area	Incident, event, and crisis management
Description of action	Access to the data collected by the sensors of connected and highly automated driving would improve 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. It would also enable the monitoring and quality control of incident management and ensure timely and consistent reporting of the finalisation of incident clearance to road users. Hence, the action would facilitate safe and efficient network operation, and benefit also the occupants of connected and automated vehicles, for instance with regard to unavailability of ODD due to the incident. To accomplish the access to the incident related data, agreements are needed among road operators, OEMs, and users of vehicles concerning the content of data (types of incidents, events, road defects, etc.), the use of data, and safeguarding of vehicle user privacy. In addition, research is needed to develop the detection of specific types of incidents, combination of manual and automated observations, and specification of C-ITS messaging for the purpose.
Timeframe	2021-2025 Standardisation and proof of concept; Development of specific incident detection; Specification and use of related hybrid C-ITS messaging; Studies, agreements and MoUs on access to data; Pilot deployment; 2026-2030 Deployment pilots
Aspect of CAD affected	Sensing, route and trajectory planning, minimum risk manoeuvre
Stakeholders affected	Road authorities and operators, OEMs, ADS providers, sensor providers, users of connected and automated vehicles
Legal prerequisites	Basically, the safety related information delegation regulation (c) already covers the early parts of the incident management chain (detection, warning) with its information types b) animal, people, obstacles, debris on the road, c) unprotected accident area, and g) unmanaged blockage of a road. If the access to other incident related data is not implemented by voluntary agreements, European regulatory action is needed
Responsibilities	Owner/champion: road authorities and operators; necessary stakeholders: OEMs, users of connected and automated vehicles, transport ministries, European Commission; other stakeholders: ADS and sensor providers
Role of CEDR/NRAs	CEDR needs to take up the issue on the European level with EC, ACEA, CLEPA and FIA as well as the European Ministries of Transport to come to a European solution similar to the sharing of safety related traffic information. NRAs need to support the process in research and pilot activities. NRAs are responsible for eventual deployment.
Risks involved	Conflicts with data related business models may slow down the process and prevent reaching an agreement on a voluntary basis.
Other relevant aspects	Minimum safety related information must also be available to all vehicles/drivers, even if the vehicle is not automated

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

IM2	Digitalisation of incident and traffic management plans
Business area	Incident, event, and crisis management/ Traffic management / Digital infrastructure
Description of action	The digitalisation of traffic circulation, traffic management and incident management plans is a prerequisite to cooperative traffic management enabling a coordinated approach by all stakeholders to ensure the best possible road network operation also at times of incidents. The action requires the description of the content of these plans in a digital format to be exchanged between the different stakeholders. The EU EIP Reference handbook for core European ITS services guidance on such plans and their exchange utilising DATEX II.
Timeframe	2021-2025: Deployment of digitalisation of traffic circulation plans, traffic management plans, and incident management plans according to European guidelines (EU EIP Reference handbook).
	2026-2030: Deployment of all new and updated traffic circulation, traffic management, and incident management plans
Aspect of CAD affected	Route and trajectory planning of connected and automated vehicles
Stakeholders affected	Road authorities and operators, traffic management operators, C-ITS service providers, fleet operators, OEMs, ADS providers
Legal prerequisites	Regulations on the quality and liability are needed.
Responsibilities	Owner/champion: traffic managers (road authorities, road operators, cities or specific traffic management operator); necessary stakeholders: road authorities and operators, cities (if not traffic managers), operators of traffic management like services (C-ITS service providers, fleet operators etc.); other stakeholders: drivers and users of connected and automated vehicles
Role of CEDR/NRAs	CEDR needs to take deployment-oriented steps if necessary to reach wide European coverage, and NRAs to deploy
Risks involved	None foreseen
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

IM3	Harmonised marking of incident sites to be correctly recognised by AVs
Business area	Incident, event, and crisis management
Description of action	Incident management practices at incident sites including markings of the site and use of protective equipment such as safety trailers vary a lot between different countries and even regions within a country depending on national and regional practices and experiences. In order to support automated driving also through incident sites, it would be very useful to have harmonised use of barriers, cones, safety trailers, temporary signs, and other equipment at incident sites during incident site protection and clearance. The harmonisation should take into account the capabilities of and requirements towards highly automated vehicles. The harmonisation effort should preferably commence as a voluntary effort within a European platform, and result in a standard. The standard should be described in highly interoperable profiles resulting in incident site markings fully and easily comprehended by automated driving systems.
Timeframe	2021-2025 Studies, piloting and harmonisation in European projects and platforms (e.g. EU EIP and ITS corridor follow-ups), standardisation of markings 2026-2030 Profiling of the standards on the EU level; deployment first by front-runners and then by others
Aspect of CAD affected	Sensing, trajectory planning
Stakeholders affected	Road authorities and operators, traffic managers of incident sites (police, traffic management operator, local contractor), OEMs, ADS providers
Legal prerequisites	The compliance to incident site marking standards should preferably be mandated, at least on the European level.
Responsibilities	Owner/champion: road authorities and operators; necessary stakeholders: traffic managers, OEMs, ADS providers; other stakeholders: rescue and emergency organisations, towage companies
Role of CEDR/NRAs	CEDR to support harmonisation work within their strategic plan. NRAs to participate in studies, piloting, harmonisation and standardisation activities as well as to deploy together with traffic managers at incident sites (actual stakeholders depending on national practices)
Risks involved	National difference in practices and organisational arrangements may slow the process.
Other relevant aspects	If European-wide harmonisation turns out to be impossible, fore-runner countries should run the harmonisation/standardisation process and deploy

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

TM1	Cooperative traffic management concept
Business area	Traffic management and control
Description of action	The concept of cooperative traffic management needs to be fully developed and implemented building on the work carried out e.g. in TM2.0, SOCRATES 2.0, and C-ITS Platform. The aim is to achieve optimum network performance, where all participants would behave towards reaching common optimum instead of individual optima. With automated vehicles, the aim can likely be reached easier. The development of the concept includes classification of roads due to network flow hierarchy, application of geofencing, establish network performance levels and triggers to engage cooperative traffic management, development of a common operational picture, and setting out the orchestration of the traffic management. As a further step, the consideration of ODDs and the actions of automated vehicles when leaving their ODD needs to be blended into traffic management to move towards "ODD aware traffic management".
Timeframe	2021-2025 Studies and pilots, cross-sectoral agreements to develop the concept
	2026-2030 Deployments in key peri-urban areas by forerunners fine-tuning the concept
Aspect of CAD affected	Route planning
Stakeholders affected	Road authorities and operators, cities, traffic management operators, service providers, fleet operators and managers, OEMs, drivers and users of connected and automated vehicles
Legal prerequisites	The status of the road authority and operator as the mobility and traffic manager of the road network needs to be ensured also legally. Traffic management plans and digital traffic regulations will be made legally binding to the operators of road vehicles and their automated driving systems. At the same time, 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. This change will increase the liabilities of the traffic managers to provide accurate and correct information to the other stakeholders.
Responsibilities	Owner/champion: road network operator (NRA, road operator, city); necessary stakeholders: traffic management operators, C-ITS service providers, fleet managers, OEMs; other stakeholders: drivers and users of connected and automated vehicles, ADS providers
Role of CEDR/NRAs	CEDR should monitor the developments and take up harmonisation actions in the domain if needed. The role of NRAs and road 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. CEDR needs to strengthen the position of road authorities in this change of roles.
Risks involved	Institutionally and legally the action is likely not very easy affecting the balance of roles, which means that it can take a long time on the European level. Locally, the action has much lower risks especially in urban areas needing cooperative traffic management to solve their problems. Risk of vendor-specific solutions.
Other relevant aspects	The MRMs are also relevant here. If the road operator finds the MRM of some vehicles as inappropriate for some parts of the road network, those vehicles may not be permitted to be operated in automated mode in the related road sections.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

TM2	Digitalise traffic rules and regulations
Business area	Traffic management and control
Description of action	The rules and regulations including current traffic management measures in force need to be digitised and made available to automated vehicles and other stakeholders in need of this information such as fleet operators and managers, police, rescue organisations, and security establishments. Specific access points to digital traffic rules and regulations (e.g. a Trusted Electronic Regulations Access Point) and ODD related infrastructure attributes need likely to be set up to facilitate the cooperative traffic management in practice as well as to provide this necessary safety-relevant information to automated vehicles in a comprehensive manner. The rules need to included restrictions imposed to the automated use of vehicles or specific use cases due to inappropriate MRMs or other reasons. High level data security is necessary for these access points.
Timeframe	2021-2025 Studies, pilots, cross-sectoral agreements, standardisation (METR standardisation already commenced); pilot deployments by fore-runners 2026-2030 Deployment; development and standardisation of Trusted Electronic Regulations Access Points or similar
Aspect of CAD affected	Planning of routes and target speeds
Stakeholders affected	Ministries, road authorities and operators, transport safety agencies, traffic management operators, police, OEMs, fleet operators and managers, ADS developers and providers, drivers and users of connected and automated vehicles
Legal prerequisites	European regulation is needed to mandate the setting up, maintaining and operating access points for digital traffic rules and regulations with specific quality and coverage.
Responsibilities	Owner/champion: Ministry or a road safety agency under it; necessary stakeholders: traffic managers, road authorities and operators, OEMs, ADS providers, fleet operators and managers, police; Other stakeholders: drivers and uses of connected and automated vehicles
Role of CEDR/NRAs	NRAs to participate in studies and pilots as well as deployment depending on their national role.
Risks involved	Risk of vendor-specific solutions.
Other relevant aspects	Physical signs are still needed as long as the system includes human driven vehicles and other human road users.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

TM3	Digitalisation of traffic management centres
Business area	Traffic management and control
Description of action	The traffic management systems have to be digitized, including the digitalisation of traffic circulation, traffic management and incident management plans (already in action **IM2**). In addition to moving to digital information systems, also the tools and processes need to be adapted to make full use of digitalisation. The processes will gradually change towards traffic management centre operators' control assisted by operator support systems and autonomous sub-systems to highly automated operation of traffic management centres, where the human operators are working in a supervisory role, only.
Timeframe	2021-2025: Development of digital traffic management centre concepts, sharing of best practices in EU EIP and ITS corridor follow-ups, automation of systems 2021-2030: Automation of traffic management, deployment of digital automated traffic management centres.
Aspect of CAD affected	Planning of routes and target speeds
Stakeholders affected	Road authorities and operators, cities, traffic management operators, traffic management system providers, drivers and users of connected and automated vehicles
Legal prerequisites	The legal framework for the operation of fully and highly automated traffic management needs to be set up
Responsibilities	Owner/champion: traffic managers (road authority or operator or city or traffic management operator); necessary stakeholders: road authorities and operators (if not traffic managers), traffic management system providers; other stakeholders: drivers and users of connected and automated vehicles
Role of CEDR/NRAs	CEDR could share best practices among NRAs, and NRAs should ensure the deployments in their country
Risks involved	Risk of vendor lock-in
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

TI1	Improved information quality for automated vehicles
Business area	Traffic information
Description of action	The data provided to highly automated vehicles needs to be of sufficiently high quality to ensure the electronic horizon to the vehicle and consequently road safety. This requires efficient quality assurance as well as effective quality assessment procedures and processes. While these are standard practices for commercial stakeholders, many road authorities still need to set up such processes. The improvement of data quality will also improve the quality and impacts of the road operator's and traffic manager's other services at the same time, benefiting also human-operated transport.

The quality assurance and assessment practices will likely lead to improved data collection and acquisition, likely utilising data produced by connected and automated vehicles. The implementation of such additional data acquisition will naturally depend on whether it is economically feasible. |
| Timeframe | 2021-2025 Development and take-up of quality assurance processes for traffic information for use by automated vehicles; Development of processes and techniques for the data chain

2026-2030 Demonstration projects; take-up and use; deployment |
Aspect of CAD affected	Sensing (electronic horizon) and planning (routes, speeds, trajectories, …)
Stakeholders affected	Road authorities and operators, cities, traffic management operators, OEMs, ADS providers, fleet operators and managers, traffic information service providers, drivers and users of connected and automated vehicles
Legal prerequisites	Legal framework for data quality liability is needed
Responsibilities	Owner/champion: Road authorities and operators; necessary stakeholders: cities, traffic management operators, OEMs, fleet operators, information service providers, drivers and users of connected and automated vehicles other stakeholders: -
Role of CEDR/NRAs	CEDR should share best practices in quality issues among NRAs, who are the main actors in deployment of the action
Risks involved	Too high costs and liability risks for increasing data quality to levels required
Other relevant aspects	Highly automated vehicles need to be aware of everything happening on the route ahead, also beyond their own sensors. Here CAVs 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. This is already the essence of action **IM1** with event data.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

TI2	Standard communication protocols related to automated vehicles
Business area	Traffic information, Road works management and planning
Description of action	Standard communication protocols need to be developed for communications of automated vehicles with traffic management centres, fleet managers, service providers TMC, fleet managers, and remote fleet supervision centres. The protocols need to provide for different types of messages from collision warnings to HD map upgrades and remote guidance of automated vehicle operation. These uses go beyond the C-ITS messaging so far developed.
Timeframe	2021-2025 Development of standardized communication protocols covering the use of different communication media and technologies; Standardisation; Development of AV-specific messages for various use cases. 2026-2030 Deployment and use by fore-runners; profiling of standards to ensure interoperability
Aspect of CAD affected	All tasks of Sense – Plan – Act
Stakeholders affected	OEMs, ADS providers, national communication agencies, telecom industry, mobile network operators, road authorities and operators, traffic management operators, service providers, users of automated vehicles
Legal prerequisites	EU regulation on using the standards and related application profiles.
Responsibilities	Owner/champion: Joint undertaking on the European level; Necessary stakeholders: European Commission , OEMs, ADS providers, national communication agencies, mobile network operators, road authorities and operators, traffic management operators, service providers; other stakeholders: users of automated vehicles
Role of CEDR/NRAs	CEDR should monitor the deployments and alert the NRAs when they need to react. NRAs should take up and use the communication protocols in their daily processes
Risks involved	Technology lock-in
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

TI3	Provision of hybrid C-ITS traffic information services
Business area	Traffic information
Description of action	The provision of short-, medium- and long-range hybrid C-ITS communications is essential for connected and highly automated driving, and thereby a priority. Thereby, the major road connections (the comprehensive TEN-T road network plus its urban links) should be covered with such services by 2030, starting earlier with the priority road connections, sections and spots.
Timeframe	2021-2025 Development and specifications and profiling of hybrid C-ITS traffic information services; large scale piloting; guidelines for use; deployment and use by forerunners 2026-2030 Deployment and use
Aspect of CAD affected	Sensing (electronic horizon, crash risks), planning of routes, target speed, trajectory
Stakeholders affected	OEMs, ADS providers, national communication agencies, telecom industry, mobile network operators, road authorities and operators, traffic management operators, C-ITS service providers, drivers and users of connected and automated vehicles
Legal prerequisites	Delegated regulations of safety-related and real-time information cover part of the services
Responsibilities	Owner/champion: road authorities and operators, Necessary stakeholders: cities, OEMs, national communication agencies, telecom industry, mobile network operators, traffic management operators, C-ITS service providers; Other stakeholders: drivers and users of connected and automated vehicles, ADS providers
Role of CEDR/NRAs	CEDR to share best practices among NRAs, which in turn support the deployment in various manners according to the local situation, e.g by equipping hot spots by short-range communications, co-funding of specific C-ITS services, etc.
Risks involved	Fleet penetration of C-ITS communication devices can be very slow
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

EN1	New infrastructure and regulations for traffic law enforcement
Business area	Enforcement
Description of action	Traffic enforcement is affected by digitalisation, connectivity, automated driving and cooperative traffic management as well as the improved cross-border and cross-entity cooperation provided by these developments. This will be accompanied also by new and modified enforcement infrastructure with connectivity and improved monitoring, prevention and mitigation of tampering activities. The technology evolution also enables the development of remote enforcement infrastructure utilising the data from connected vehicles concerning their speed, weight, environmental category, etc. Due to the sensitivity of this kind of enforcement with regard to privacy and user acceptance, the applications will in the short-term be limited to specific vehicle fleets or in connection with traffic insurance schemes and road user charging. In all of these cases, the drivers and users of the connected and automated vehicles will have to give their consent to remote enforcement when starting to use the service. As speeding is crucial to road safety, the overrides of the intelligent speed adaptation system mandatory to new models of cars sold in the EU from 2022 could be a target of enforcement.
Timeframe	2021-2025 Connected speeding cameras with necessary accuracy to be deployed (also for human operated vehicles); Monitoring of tampering activities; Development of effective prevention and mitigation measures against tampering. 2026-2030 Development of remote enforcement of connected and automated vehicles
Aspect of CAD affected	Planning of routes and target speeds
Stakeholders affected	Police, enforcement equipment providers, road authorities and operators, cities, traffic management operators, road safety agencies, insurance companies, fleet operators and managers, road use charging operators, OEMs, ADS providers, mobile network operators, drivers and users of connected and automated vehicles
Legal prerequisites	The legal framework for the use cases of remote enforcement needs to be developed
Responsibilities	Owner/champion: police; necessary stakeholders: road safety agencies, road authorities and operators, traffic management operators, insurance companies, fleet operators and managers, road use charging operators, OEMs, ADS providers, enforcement equipment providers; other stakeholders: drivers and users of connected and automated vehicles
Role of CEDR/NRAs	Depending on the national practices and enforcement cooperation, NRAs support the deployment in an appropriate manner
Risks involved	Privacy concerns
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

EN2	Environmental enforcement utilising geofencing and other tools
Business area	Enforcement
Description of action	Due to the need to mitigate climate change and greenhouse gas emissions as well as to reduce the public health impacts of harmful emissions, regulations and measures to monitor and mitigate the emissions of vehicles are being implemented. A recent European example is the publication of Urban Vehicle Access Regulations. Such regulations require effective enforcement tools to ensure user compliance. Geofencing is an excellent tool for this purpose with regard to connected and automated vehicles, and cooperative traffic management in general. With geofencing, automated vehicles can be allocated access only to the parts of road network allowed for vehicles belonging to its environmental category or using specified power mode (type of energy used in powertrain). The environmental category will also be indicated by V2I messaging and checked in the future by infrastructure sensors such as cameras for all vehicles.
Timeframe	2021-2025 Regulation of data exchange of environmental information of vehicles with infra for geofenced areas; Upgrade of CCTV for identification of environmental vehicle categories where necessary; Preparation of legal framework for enforcement. 2026-2030 Guidance to connected and automated vehicles on power mode for local environmental management
Aspect of CAD affected	Planning of routes, selection of power mode
Stakeholders affected	Police, enforcement equipment providers, road authorities and operators, cities, traffic management operators, OEMs, ADS providers, mobile network operators, drivers and users of connected and automated vehicles
Legal prerequisites	The legal framework for environmental enforcement and the use of related geofencing needs to be developed and put in place.
Responsibilities	Owner/champion: cities; necessary stakeholders: police, enforcement equipment providers, road authorities and operators, traffic management operators, OEMs; other stakeholders: ADS providers, drivers and users of connected and automated vehicles
Role of CEDR/NRAs	Depending on the national practices and enforcement cooperation, NRAs support the deployment in an appropriate manner
Risks involved	Privacy concerns
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

NR1	General physical road design changes
Business area	New roads planning and building
Description of action	The increasing use of connected and highly automated vehicles means that the options for road use will be broader and more diverse in the future. There will be choices between the shared use of roads between different traffic modes (automated or human-operated) or differentiating use at different time slots and on the other hand dedicated lanes for specific use cases, like e.g. platooning on important freight routes. Planning of new roads but also planning of road upgrades need to consider and make provisions for mixed traffic and highly automated driving. It is evident that road design has to integrate the digital infrastructure needed by connected and automated vehicles. New design guidelines will need to be developed for planning of new roads as well as for upgrades of existing ones. One element that would have a tremendous impact on new road planning standards but also budgets is whether or not dedicated lanes should be provided anywhere or for any use case. Design guidelines should therefore provide indications in which areas, road types, use cases and/or traffic volumes this could be a recommended solution. Intersection and ramp designs as well as bridge design standards likely need to be adapted to consider the safe and efficient operation of platooning. The design guidelines also will consider that while the needs for parking spaces will decrease over time, additional areas for deliveries of all kinds and sizes as well as passenger pick-up and drop-off points will increase. The BIM (building information modelling) methodology will ensure the parallel development of a so called digital twin of the new road that includes all necessary design, material and operational data for each asset.
Timeframe	2021-2025 Research on road design requirements of connected highly automated vehicles; cross-sectoral discussions on priority topics identified; Piloting of infrastructure design elements at test sites and sections 2026.2030 Pilot deployments on open roads; Incorporation of digital infrastructure elements in road design guidelines
Aspect of CAD affected	All elements of sense – plan - act
Stakeholders affected	Road authorities and operators, cities, traffic management operators, road planning consultancies, road building contractors, OEMs, ADS providers, drivers and users of connected and automated vehicles
Legal prerequisites	The legal framework may need to be adapted depending on national situation
Responsibilities	Owner/champion: road operators (NRA/road operator/city); necessary stakeholders: traffic management operators, road planning consultancies, road building contractors; other stakeholders: OEMs, ADS providers, drivers and users of connected and automated vehicles, research and academia
Role of CEDR/NRAs	CEDR needs to share best practices and promote harmonisation and standardisation on road design for highly automated vehicles and mixed traffic. NRAs will specify the design changes and deploy them in practice.
Risks involved	The quick technology evolution of highly automated vehicles brings uncertainties concerning when the road authorities and operators have "full" certainty of the actual requirements of the automated vehicles.
Other relevant aspects	

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

RW1	Harmonised management of road works sites
Business area	Road works management and planning
Description of action	The roadworks should be planned, implemented, and managed in a way that makes them easy for the vehicle drivers as well as highly automated vehicles to negotiate in a safe manner. This calls for harmonisation on the European and global level concerning the markings, work zone protection and 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. Both stationary and mobile roadworks should be equipped with hybrid C-ITS communications, and thereby guidelines for their deployment and use are to be developed. The deployments, operation and maintenance of roadworks warning and information C-ITS service will be included in the contracts with related contractors. Automated safety trailers and road works vehicles will be used increasingly for ensuring the safety of roadworks personnel. Connected and highly automated vehicles will be used 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. 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.
Timeframe	2021-2025: Marking of road works sites – studies and standardisation; Management - fine-tuning of processes, proposal for harmonisation; C-ITS warnings: specification and profiling of hybrid C-ITS road works warnings, pilot, guidelines for use, deployment and use by forerunners 2026-2030 Marking - Profiling of the standards on the EU level, deployment; Management - deployment pilots for harmonised management; C-ITS warnings - Inclusion in road works contracts; deployment and use on selected corridors and networks
Aspect of CAD affected	Sensing (identification of road works site, driving lane), Planning of target speed and trajectory
Stakeholders affected	Road authorities and operators, cities, traffic management operators, road works contractors, OEMs, ADS providers, mobile network operators, drivers and users of connected and automated vehicles
Legal prerequisites	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.
Responsibilities	Owner/champion: road operators (NRA/road operator/city); necessary stakeholders: traffic management operators, road works contractors, OEMs, ADS providers; other stakeholders: mobile network operators, telecom industry, drivers and users of connected and automated vehicles
Role of CEDR/NRAs	CEDR shares best practices among NRAs and promotes standardisation. NRAs specify, plan and implement
Risks involved	The quick technology evolution of highly automated vehicles brings uncertainties about the actual requirements of the automated vehicles.
Other relevant aspects	

MA1	Legal framework for driverless maintenance vehicles
Business area	Road and winter maintenance
Description of action	Unmanned vehicles are legally not allowed on European roads yet except for some countries. This also includes maintenance vehicles like safety trailers, mowing robots, or automated snow ploughs. While supporting automated functions are helpful in road maintenance, only driverless maintenance vehicles for safety critical tasks are able to provide the actual safety improvements for operational workers and cost-reduction gains for the maintenance contractors. 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.
Timeframe	2021- 2025 Provision of legal framework for initial use cases like driverless safety trailers and mowing robots; Validation in pilot projects 2026-2030 Legal framework for additional use cases; Continuous deployment of driverless safety trailers and mowing robots for particularly safety critical situations
Aspect of CAD affected	All stages of sense – plan – act
Stakeholders affected	Transport ministries, road safety agencies, road authorities and operators, cities, road and winter maintenance contractors, OEMs, ADS providers
Legal prerequisites	Described above
Responsibilities	Owner/champion: Transport ministries or road safety agencies (depending on national situation); Necessary stakeholders: road authorities and operators, cities, road and winter maintenance contractors, OEMs, ADS providers; other stakeholders: -
Role of CEDR/NRAs	CEDR should support the action. NRAs should support and utilise the automated maintenance vehicles in their daily operation and contracts
Risks involved	Technology or vendor lock-in
Other relevant aspects	

5.2 Research and innovation

The focus of actions in the next five years will be in the domain of research and innovation as the technology solutions for SAE level 4 highly automated driving are still under development. Here the Horizon Europe programme and its automated driving related research activities play an important role. The CCAM Partnership (ERTRAC 2020) will play a major role in the preparation and planning of these activities, and NRAs should thereby actively participate in the work of the partnership. The research and innovation actions of NRAs should be aligned with those occurring in Horizon Europe strengthening the impacts of the actions.

The draft Strategic Research and Innovation Agenda SRIA (CCAM Platform 2020) prepared primarily for Horizon Europe proposes three major research and innovation actions for connecting the vehicle to the infrastructure, the main focus of the NRAs: 1) Fleet and traffic management in a CCAM eco-system, 2) Physical and digital infrastructure, and 3) Connectivity and Cooperative Systems.

Concerning fleet and traffic management, the existing mixed traffic of conventional and connected and automated vehicles on the roads needs to become safer and more operational (efficient) within the network infrastructure that should in return possess a CCAM hosting

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

capacity. This can be achieved by designing, developing, conducting simulations, testing and piloting on: (CCAM Partnership 2020)

- A well optimized (or optimizable) system for the transport of people and goods based on multiple usage/application scenarios to cover different use cases, environments and technological readiness;
- Focussing on the identified societal needs and balancing out with those of individual users;
- Identifying gaps in existing technology development and update with all (well collected / reliable) information on the technological development in order to foster vehicle integration that optimises the use of new technology;
- Developing reliable simulation/modelling tools for the move towards a CCAM integrated mobility system that is agile and able to 'host (unknown yet) technological developments, services & business cases
- Develop and test (proofs-of-concept) new management schemes and governance models (including regulatory aspects) and business models to operate mobility systems enabled by CCAM (including Interaction between different modes of travelling) and derive guidance (e.g. knowledge base) for authorities.
- Develop services for both remote guidance or operation as well as local ad-hoc coordination of CCAM-vehicles (or at least information/advice for automated vehicles) in order to increase and control the automation level of intersections and/or other potential points of hazards
- Develop services that optimise traffic management enabled by CCAM while also attaining the targets for improve mobility patterns, in terms of reliability, congestion and carbon footprint
- Develop a CCAM integrated mobility system that supports traffic management with a range of communications deployed among traffic actors aiming at better manoeuvres coordination
- Use a step-wise approach in assessing possible future traffic management strategies enabled by CCAM by developing mixed traffic micro- and meso-simulation models (including dedicated lanes; priorities at intersections etc.)
- Develop real-time traffic optimisation enabled by CCAM services and based on the integration of tools such as HD Maps, machine learning and achieving more efficient route guidance and use of space within the mobility network (parking, dedicated lanes etc.)
- Extending the scope of fleet & traffic management system to integrate the management of the mobility demand (capacity aware demand management)
- Coherent conceptual development of extended (operational) fleet & traffic management towards integration (demand responsive capacity management consisting of dispatching, routing, pooling, matching, pre-positioning and rebalancing)

With regard to physical and digital infrastructure (PDI) related to connected and automated driving, the SRIA proposes the following research topics: (CCAM Partnership 2020)

- Identify, develop and agree on a minimum set of adaptations incl. no-regret measures necessary at the infrastructure side (physical, digital, operational) to support CCAM and especially mixed traffic (automated and conventional vehicles co-existence) situations
- Define classifications of PDI in relation to ODD
- Harmonisation of information to be exchanged: type, format and content of information coming from external parties must be unambiguously defined.

- Infrastructure operator data classification schemes to manage various levels of external data provision capabilities (road authorities and operators on a national, regional and city level).
- Provide infrastructure data via relevant communication systems in a harmonized way (e.g. in the same format (semantics and syntactics) as well as in the same way, harmonizing data provision in every country/region/city).
- Simulations and testing to investigate how PDI can support CCAM and which are the effects on traffic efficiency, traffic safety and traffic management (e.g. identification and performing of minimum risk manoeuvre)
- Studies and concepts regarding business models in order to assess and stimulate PDI investments and operation of services
- International communication standards for highly automated driving systems enabling uninterrupted operation across borders.
- European cross-border pilots to investigate and develop secure and trustworthy interaction between vehicles, infrastructure and third-party services
- The already substantial regulatory framework for infrastructure across Europe has to be captured and documented to enable coordinated and productive progress on this field
- Development of processes how to transfer relevant static and dynamic road and PDI information into HD-maps and how to update them
- Development of automated road and PDI monitoring and maintenance procedures to assure trust in the PDI performance
- Develop and describe PDI-CCAM architectures and its needed (or missed) technology R&D activities
- Further develop and use the concept of ISAD, regularly update road classification schemes, create or extend living labs with PDI and demonstrate the added value coming from road operators for CCAM.
- EU-wide/global harmonisation for infrastructure support classification to support highly automated vehicles
- Research on questions to address: What are the roles and responsibilities of the different stakeholders of PDI for CAD? How to define the trust and quality of data. Who operates the services? How to ensure continuity between those different environments?

With regard to connectivity and cooperative systems, the following topics were related to automated driving: (CCAM Partnership 2020)

- Define connectivity availability and performance requirements for Automated Driving functions (robustness and redundancy, Quality of Service [QoS], resilience etc.), meeting requirements of functional safety and safety critical applications
- Ensure (cyber)secure and safe communications respecting privacy and various levels of trust
- Develop feasible and sustainable concepts for road infrastructure coverage (short range and cellular long-range) of connectivity to enable CCAM services; This lack of communication availability on the road network will lead to a reduced functionality for automotive use cases using data from external sources through V2X communication (such as safety critical manoeuvres or teleoperation in deadlocks or end of traffic jam signalling).
- Analyse and assess potential measures to improve communication performance (e.g. correctness and latency) for multi-brand configuration of HGV platooning

The lists show that many of the topics are related to the recommended actions of chapter 5.1.

Page 105 of 128

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Thereby, road authorities should be active and devote resources in participating in the upcoming research projects on the topics listed. Participation not only provides networking and educational opportunities but provides a possibility to steer development and address specific subtopics in the interest of road authorities. For these reasons, it is also important for the road authorities to actively participate in the work of the CCAM partnership, which is proposing the SRIAs to the Horizon Europe programme.

As the lists above shows, the research questions are still on a quite general and basic level, especially with regard to physical and digital infrastructure. They also clearly show that increased automation of driving results in increasing needs for harmonisation of both physical and especially digital infrastructure. The harmonisation of digital infrastructure is easier as the deployment of it is still largely ongoing and can still be easily influenced. Harmonisation of and changes in the existing physical infrastructure often carry high costs, and the NRAs need to be certain of their necessity before making decisions to invest in such actions.

A key topic for infrastructure related research in the near future is linked to the ODD (Operational Design Domain) of the highly automated vehicles coming to the market and how the ODDs for different highly automated driving use cases will evolve in the next decades. The ODDs will determine where the road authorities and operators need to invest if they wish to benefit from highly automated driving on their roads (the benefits are a separate research topic also addressed in the SRIA). Research is needed to determine the key values of the ODD related physical and digital infrastructure attributes. A major challenge is that due to fast technology development, the ODDs evolve and these key values and even the attributes themselves likely change in time, and this kind of research needs to be carried out on a regular basis until the technology is mature and settled. It is also important to devote research efforts to the edge cases of ODD i.e. environments and situations, where the risk of ODD termination is high, and thereby specific attention needs to be given in order to facilitate continuity of ODD along the road and networks.

Another key research topic is to understand the road design requirements of connected highly automated vehicles. The issues here are quite diverse. Does platooning require changes in the designs of bridges, on-ramps, off-ramps, or other road elements? How to solve the possibly increased rutting and roughing problem due to reduced tyre wander across lane width? How to design safe and efficient passenger pick-up and drop-off points for driverless vehicles? Should specific road infrastructure changes be made to better accommodate automated maintenance vehicles?

A key research topic related to highly automated vehicles is the development of an optimal minimum risk manoeuvre. For the safe and efficient operation of the road transport system it is essential that these minimum risk manoeuvres carried out at the end of the ODD will not cause danger to other road users nor should they move the roads to a standstill. Currently published proposals such as using stopping on driving lane are unacceptable, and vehicles with such minimum risk manoeuvres should not be permitted to operate in automated mode on high-speed roads. Hence, research and related piloting actions should be carried out in cooperation with the automotive industry to come up with optimal minimum risk manoeuvres with regard to different automated driving use cases in different operating environments.

Development of HD map processes is also a key research topic from the point of view of the road authorities and operators. The big issue is to ensure that the contents of the HD map are always up-to-date, which has also on impact on the road authority and operator processes to provide to HD maps real-time information on the changes made by or for the road authorities and operators to the road transport system including the road, roadside systems, road equipment, traffic management plans, etc. It is in the road authority and operator interest to safeguard their interests in these processes, and thereby participate in related research and development actions.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Similar motivations encourage road authority participation in research activities developing the cooperative traffic management concept. Here the role of the road authorities is even more central as they are regarded as the natural choice for the orchestrator of cooperative traffic management.

HD maps are the fundament for the digital twin of the road transport system, and road authorities and specifically traffic management operators need to carry out research on the feasibility of real-time digital twins which include traffic flows. Research is also needed to provide their proof of concept and also to pilot the promising solutions,

Finally, cybersecurity needs to be addressed as it is more than likely that cyberattacks will utilise the various opportunities provided by connected and highly automated vehicles. Thereby, also the road authorities and operators, cities and traffic managers need to ensure their own systems, connections and interfaces are and remain secure. With regard to research, this means inclusion of cybersecurity as one of the topics addressed in test areas and all relevant pilots.

5.3 Regulation and standardisation

Regulation is needed to enable automated operation of vehicles and traffic management systems in specific operating environments to clarify their operational conditions and to clearly determine the liabilities of the stakeholders involved. Regulation may also be needed to ensure that the necessary harmonisation, standardisation, and cross-stakeholder data exchange for the safe operation of highly automated vehicles be accomplished across borders. Many of the regulation needs listed below would be unnecessary if the same end result could be reached by voluntary agreements between the stakeholders involved, but past experiences have shown that such agreements are difficult to reach with the required pan-European geographical and stakeholder coverage.

Regulation is likely needed to mandate the OEMs to provide detailed information of the ODDs of their vehicles to the managers and operators of the physical, digital and communication infrastructures. Likewise, the physical, digital and communication infrastructure managers and operators are likely regulated to provide corresponding information of their infrastructure support level for automated driving to OEMs and fleet operators and managers,

It is likely that minimum risk manoeuvres (MRMs) need a legal framework describing the acceptable MRMs in different operating environments. The road authorities and operators including cities need the right to deny on their roads and streets the automated use of such vehicles, for which the MRM does not fulfil their requirements.

The legal framework needs to be set in place for ensuring the data quality in HD maps and the liabilities involved. Regulation could also be needed for the OEMs, fleet managers and other stakeholders governing the data from connected and automated vehicles to provide feedback about the anomalies in HD maps detected by their vehicle fleets as well as for the road operators to make their existing data available for HD road map purposes.

The status of the road authority and operator as the mobility and traffic manager of the road network needs to be ensured also legally. Traffic management plans and digital traffic regulations should be made legally binding to the operators of road vehicles and their automated driving systems. Regulations on the quality and liability for digital incident and traffic management plans are also needed. At the same time, the vehicle manufactures, automated driving system providers, and fleet managers of highly automated vehicles should be mandated to share safety, traffic management and ODD related data to the traffic managers of the networks, which they are using. These changes will increase the liabilities of the traffic managers to provide accurate and correct information to the other stakeholders.

European regulation is also needed to mandate the setting up, maintaining and operating access points for digital traffic rules and regulations with specific quality and coverage.

The compliance to incident and road works site marking standards should preferably be mandated, at least on the European level. Such is the case also for using the automated vehicle communication protocol standards and related application profiles.

The legal framework for is needed for many cases of automated operation from the part of the road or other transport authority and operator. These include the operation of fully and highly automated traffic management with no human operator in the loop, the use cases of remote enforcement, and environmental enforcement including the related use of geofencing.

The legal framework is needed for automated maintenance vehicle use cases like driverless safety trailers and mowing robots.

At the world level, advice, regulation and standardisation on the road transport systems takes place most prominently through the United Nations Economic Commission for Europe (UNECE) which is the "guardian" of the international conventions on driving (the Geneva Convention of 1949 and the Vienna Convention of 1968) and has responsibility for developing and approving international standards for vehicles. The overall responsible body for transport at UNECE is the Inland Transport Committee, but all important work items are delegated to subsidiary Working Parties. In the area of road vehicle automation, there are two relevant working parties with formal decision-making responsibilities, WP.1 and WP.29. Both those working parties have an increasing focus on automation. At both WPs, only "contracting parties", i.e. signatories of the convention (member states and the EU), have voting rights, but recognised NGOs can participate in the discussions.

UNECE WP.1, The Global Forum for Road Traffic Safety has responsibilities for promoting the Geneva and Vienna Conventions, particularly the latter. Under active discussion is the need to amend the Vienna Convention to permit a non-human, i.e. an ADS, to drive a vehicle. The process to develop an amendment to the Convention to that purpose has already begun. Overall, WP.1 deals with rules of the road, driver regulation, recommendations on driver and rider behaviour, road user safety and road signs and signals. The last is of course extremely relevant to road authorities. In 2018, WP.1 adopted a *Resolution on the Deployment of Highly and Fully Automated Vehicles in Road Traffic*, laying out a set of overall principles for the safe deployment of AVs. More recently it has been focussing on developing a resolution on other activities, i.e. non-driving related activities, that can be allowed under highly automated (SAE Levels 3 and 4) driving. It is also discussing remote operation of automated vehicles. Member state participants are typically lawyers from national transport ministries. Road authority participation is negligible, but through the International Organization of Motor Vehicle Manufacturers (OICA) there is active representation of vehicle manufacturer interests.

UNECE WP.29, The World Forum for Harmonization of Vehicle Regulations develops harmonised technical regulations for vehicles at a global level. In the EU, once approved, those regulations automatically go into the Whole Vehicle Type Approval process. Thus there is automatic adoption of UNECE decisions on new vehicle standards for the EU. Parallel to the WP.1 Resolution, WP.29 also adopted its own *Framework document on automated/autonomous vehicles* in 2019, with a revised version issued in March 2020. The document from WP.1 and the one from WP.29 cover much the same ground, so that it can be noted that it is a pity that they have not been merged into a single statement of principles. This is a reflection of the lack of joint working between the two working parties. The other most notable output of WP.29 in the domain of automated driving is the first ever agreed set of standard for a Level 3 system in the shape of the regulation for an Automated Lane Keeping System (ALKS). This system, also known as "Highway Chauffeur, was authorised in June 2020. It allows hands-off and feet-off highway driving by an ADS at speeds up to 60km/h. It can be noted that the fallback for this system, in the event of the human failing to respond to a

request from the vehicle to take over the driving task, is a Minimum Risk Manoeuvre of stopping in lane. The specified ALKS system will automatically become legal in the EU. Once again, the road authorities do not appear to be at the table in the relevant discussions. The main expertise contributing to the work of WP.29 and its subsidiary groups is vehicle engineering. OICA has substantial input into the discussions.

The structure of the UNECE working parties and subgroups in the area of automated driving is depicted in **Figure *11***. The recently constituted groups under GRVA, especially FRAV, are relevant to the road authorities. It is likely that the ACSF group will be disbanded in the near future.
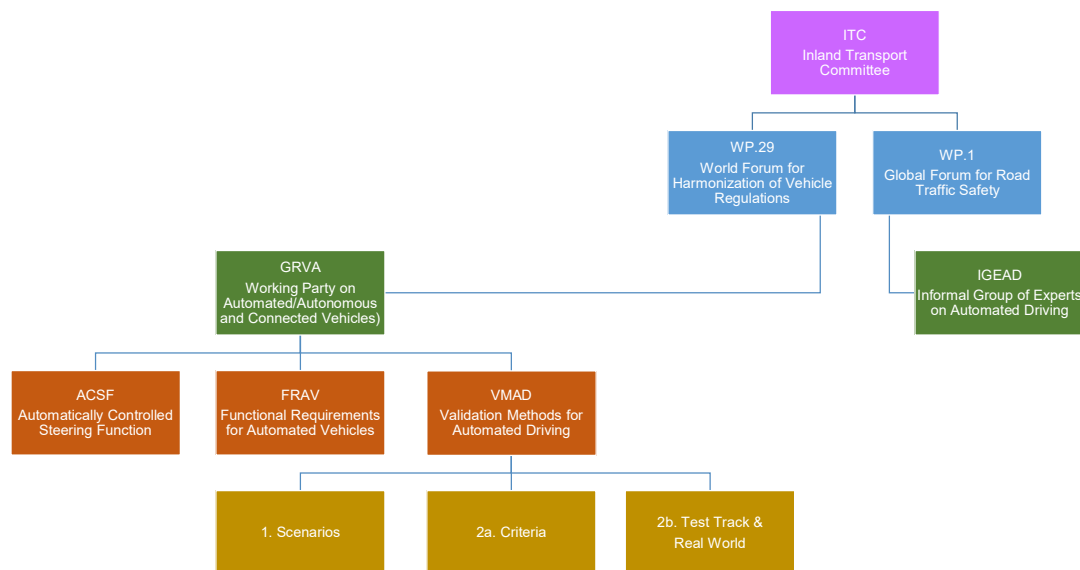
Figure 11: Working Groups on automation at UNECE

Standardisation actions are taking place in Europe in CEN and ETSI as well as globally in ISO. Some relevant groups and committees are mentioned below, based on the recent standardisation snapshot provided by SFS (2020).

CEN/TC 278 Road transport and traffic telematics is responsible for the development of European standards and technical specifications in the domain of Intelligent Transport Systems (ITS). The work of this TC is and has been closely connected with the implementation of the ITS Directive 2010/40/EU.

CEN/TC 226 Road equipment is very relevant to automated driving. The WG 12 (Road interaction – ADAS / Autonomous vehicles) of the TC 226 has in its scope, the necessity to understand the interactions between the road equipment and automated vehicles. It has also the goal to develop a vision and associated functional and operational requirements enabling the deployment of a smart system ensuring the consistency between the road infrastructure and the embedded automated vehicle system. WG 12 does not have any working items, yet.

ISO/TC 204 Intelligent transport systems has several working groups dealing specifically with automated driving. The WG 08 Public transport/emergency is working on automated driving bus standardisation. The WG 14 Vehicle/roadway warning and control systems has working items such as automated valet parking systems and low-speed automated driving systems for limited operational design domain. The WG 19 Mobility integration develops ITS standards products supporting enhanced integration of services and applications of ITS solutions focused on the urban ITS and mobility integration. Potential preliminary work items

of WG 19 include Management for Electronic Traffic Regulations (METR) and traffic management systems – TM interfaces and information. It has already worked on architecture for automation.

ISO/TC 22 Road vehicles has the SC 33 Vehicle dynamics and chassis components, which works on lateral and longitudinal vehicle dynamics and controls/systems/functions affecting vehicle dynamics, such as chassis components, wheels, steering, brakes and suspension. This includes automated driving, means and performance of collision avoidance and mitigation. Of the ten working groups directly under SC 33, the WG 3 Driver assistance and active safety functions and WG 9 Test scenarios of automated driving systems are related to automated driving.

ETSI/TC ITS develops standards related to the overall communication architecture, management, security as well as the related access layer agnostic protocols: the physical layer, network layer, transport layer and facility layer. Applications include road safety, traffic control, fleet and freight management and location-based services, platooning providing driver assistance and hazard warnings and supporting emergency services. The WG 5 works specifically for security related work items. Many of the solutions affecting road authority core business including physical and digital road infrastructure solutions are being and will be standardised in the standardisation organisations. The work in the different committees and working groups tend to be run by private companies with their interests on promoting their own products and services in full scale deployment. It is in the road authorities' own interest to safeguard their interests in standardisation to ensure that the solutions standardised will be as technology and vendor agnostic as possible to guarantee competitive markets and thereby affordable products. Hence, the road authorities should participate in these groups and committees either individually or by sharing the responsibilities of participation with like-minded road authorities and operators.

Key topics for standardisation participation are those affecting NRA core business and likely having major cost implications for the NRAs. Examples of such topics related to the priority actions are ODD specifications, determination of minimum risk manoeuvres, markings of incident and road work sites, and properties or road signs and markings.

While not receiving sufficient priority nominations at the survey, for the drivers and users of connected and automated vehicles it would be very important to use same pictograms in warnings at roadside VMS and in-vehicle terminals to reduce confusion and thereby to increase safety. Thereby, harmonisation and standardisation of the traffic information and especially warning pictograms would be important.

.

5.4 Deployment and operation

Most of deployments will be carried out by the NRAs, when they are fully aware of the needs from them as well as the related benefits and costs. Some deployments may be carried out as pilot deployments by fore-runner NRAs to accumulate experiences. It is extremely important to share the deployment and operation related experiences within NRAs and other road operators to avoid mistakes and poor investments. CEDR could and should be the platform for this experience sharing. Many of the deployment and operation practise adaptations recommended in the priority actions are useful even before highly automated vehicles are rolled out in meaningful numbers. Hence, these can and should be deployed already now.

While most physical infrastructure investments are not yet relevant expect for pilots, some actions to deploy and take up in operations are already recommendable. To ensure road-side machine readability by vehicle sensors, when purchasing new VMS or replacing old VMS at

end of their lifecycle, acquire VMS with light pulsing compatible with vehicle sensors. It is also valuable to carry out good road sign and marking maintenance processes and to provide enhanced maintenance and quality management on selected priority roads to ensure consistent and minimum quality of solid or dotted lines and symbols painted on the pavement.

Data from existing digital road maps of the road authorities and operators should already be made available to digital map and service providers. Road authorities need to ensure the cybersecurity of their own services, systems, databases and interfaces. They should also monitor cybersecurity issues and react when needed.

NRAs should also proactively attract digital expertise participate actively in relevant national and international platforms and key projects related to highly automated driving for learning purposes.

The NRAs are recommended to digitize their traffic circulation plans, traffic management plans, and incident management plans according to European guidelines (EU EIP Reference handbook). The development and deployment of digital traffic management centre concepts should be started or continued with increased automation of the traffic management and operator support systems. Pilot deployments are recommended for provision of traffic rules and regulations by fore-runner NRAs.

All NRAs should implement quality assessment and assurance processes and technologies for traffic information. This is extremely useful already today for manually operated vehicles as the benefits of traffic information increase for higher information quality.

Hybrid C-ITS traffic information and warning services should be provided by or with support from NRAs as the percentages of connected vehicles increase.

In enforcement, connectivity of automated enforcement stations and implementation of environmental monitoring should be initiated.

5.5 Stakeholder cooperation

Making highly automated driving a reality on European roads requires cooperation of various stakeholders, and their variety depends on the use case and operating environments. The stakeholders include, among others, OEMs, ADS providers, HD map providers, fleet operators and managers, road authorities and operators, cities, traffic management operators, road planning, building and maintenance contractors, road and vehicle equipment providers, telecommunications industry, mobile network operators, police, rescue operators, transport safety agencies, ministries, the EC, and standardisation bodies.

Cooperation is a useful way of coping with a rather dynamically evolving future. Some executives of global vehicle manufacturers have publicly stated that they cooperate between different world regions because "no one has a valid picture of what will happen with level 3 or level 4 and so facing this uncertainty jointly gives us a better feeling". In other words, expectations towards successful stakeholder cooperation should not follow a reductionist picture, in which individual representatives of cooperation partners would have a valid picture where the journey will lead.

There is a clear need for stakeholder cooperation with regard to the ODDs and ISADs or in general the infrastructure support levels provided by the road authorities and operators. The attributes need to be agreed in dialogue between OEMs and road authorities and operators, and this needs to be continuous taking on board the evolution of the ODDs. However, agreeing on attributes needs specific understanding of future decision situations in order to provide sustainable added value. A concept of sharing data without understanding the specific (future) decision situation involves significant risk of data graveyards. Stakeholder cooperation

typically involves having a dynamically evolving vision of one's own role and the changing roles in a future landscape of value service providers. Maintaining one's traditional role as an NRA might interfere with fruitful stakeholder cooperation – at least when it comes down to some forms of liability and risk taking in case of errors in the data.

HD map related processes including the feedback loops and other measures to keep the maps updated at all times also require close cooperation with the stakeholders involved. The provision and exchange of data on incidents, events, crises and other disturbances to the transport system requires close cooperation with all stakeholders.

Cybersecurity is another domain where cross-sectoral agreements on threat identification, solutions and responsibilities are essential. This also applies to the development of standardized communication protocols covering the use of different communication media and technologies.

The whole concept of cooperative traffic management is built upon the cooperation of key stakeholders.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

6 Conclusions

The aim of the report was to identify the needs for the national road authorities (NRAs) to adapt their core business due to deployment of connected and highly automated driving, and to recommend a set of actions for those adaptations. The core business areas considered were:

- Physical road infrastructure
- Digital infrastructure
- Operations and services
    - incident and event management
    - crisis management
    - traffic management and control
    - road maintenance
    - winter maintenance
    - traffic information services
    - enforcement
    - road user charging
- Planning, building, heavy maintenance
    - new roads planning and building
    - road works planning and management
    - heavy maintenance planning
- New business.

The results of the previous work in MANTRA and other relevant projects and actions, and the analysis of those utilising the Multi-Level Perspective led to the listing of 92 actions. The CEDR workshop held to validate the actions gave a strong message to provide a shorter list of priority actions. While the proposed actions were all after some adjustments considered valid, only a much shorter list of actions was considered to be useful for the recommended NRA roadmap to be discussed by the road directors in CEDR. Hence, MANTRA organised a web survey to prioritise the selected actions selected. There were 45 respondents to the survey with about half representing NRAs and related ministries and the other half non-NRA experts on connected and automated driving. Based on the survey results and the resolution of some overlaps between the actions, a final set of 22 priority actions was identified. A detailed description of these actions has been provided including, among others, the stakeholders involved and CEDR/NRA roles and tasks.

One further action has been identified in the final stages of the project while reviewing the challenges to enforcement due to the introduction of automated freight vehicles. Although this challenge has not been discussed in a workshop nor in communication with stakeholders, it is considered to be significant. The issue is that automated freight vehicles will have to be aware of their gross weight and axle loadings when deciding on a route. They will have to consider whether that gross weight and the individual axle loadings exceed what is permitted in all sections of the route, particularly on bridges and viaducts. Thus such vehicles would have a dynamic ODD with one set of routes available when empty or lightly loaded and a smaller set of routes available when fully loaded. Such would be the case also for vehicles carrying hazardous materials or abnormal loads. The consequent action is listed below under "study and learn".

The CEDR members responsible for the supervision of MANTRA requested to classify the actions in a way useful to the NRAs and CEDR. Thereby, we have classified the actions in three major categories based on our own expertise as following:

- Actions with no regret – actions useful also for human-operated vehicles to be carried out due to present needs and other developments;

- Study and learn – actions to find out more about the technology, operation, benefits, costs and implementation issues in order to understand the potential, restrictions and feasibility of automated driving;
- Key actions for deployment – actions to safeguard NRA interests and with major future impact on NRA investments and operations.

None of the actions purely belong to only one category. All of the actions include elements of study and learn, for instance. The classification relates to the most essential nature of the action.

The actions with no regret contain the following actions (the action number from chapter 5.1):

- Machine readability and digital twins of road signs (PI2)
- Road markings of sufficient retro-reflectivity in different conditions (PI3)
- Provision of road network related data to HD maps (DI2)
- Human resources with digital expertise (DI5)
- Digitalisation of incident and traffic management plans (IM2)
- Digitalisation of traffic management centres (TM3)

The actions listed above are recommended to be carried out even with no highly automated vehicles as they will be beneficial to service providers, fleet operators and connected vehicles in addition to the NRAs' own processes and operations. It needs to be pointed out that "no regret" should not be mistaken for "involving no risk". Many digitalisation initiatives involve significant risk both in terms of competing technologies and increasingly ambiguous technology readiness levels. Depending on the strategic position of some NRAs, a focus on only this first set of actions might involve additional risks of losing or not attracting highly qualified staff with digital proficiency. Therefore, the risk of not facing some of the tricky challenges might come through the back door of missed opportunities or high external dependency in not attracting and keeping digital competences.

Typically, any value added in providing information to partners in a varied ecosystem of stakeholders internally and externally depends on understanding the specific context of those who make decisions on the basis of digital information. Traffic management might involve entirely new roles such as predictive maintenance, contribution to greening Europe, maintaining economic strength in a world with jammed logistic hubs, coping with increasingly severe weather conditions, demographic changes in driver population, high intensity of digitally enhanced rests, and travellers avoiding air travel or train travel due to COVID-19 follow-up scenarios. Thereby digitalisation in traffic management certainly not a trivial issue.

Studying and learning within several departments in a specific NRA would profit from in depth studying and providing ODD and ISAD specifications for some key priority areas on the road network and decision algorithms within a specific NRA for early forms of assisted vehicles as an internal preparation exercise on digitalization. The exercise should also aim at mitigating issues with e. g. minimum risk manoeuvres and support future proactive alignment with vehicle manufacturers and service providers.

Furthermore, it is important to develop a kind of mental model and organisational vision on what a specific NRA wants to grow into in a time of digitalisation and ecologically challenging political goals – even with a slow uptake of automated functions in vehicles. In other words, the individual actions should never be picked solely on the basis of individual projects or organisational silos but also for their contribution to a dynamically evolving vision and mission concerning digitalisation in NRAs.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

The actions of study and learn include the following:

- Ensuring up-to-date content of HD maps (DI1)
- Cybersecurity issues for connected and highly automated vehicles (DI3)
- Information provision on incidents, events and crises (IM1)
- Harmonised marking of incident sites to be correctly recognised by AVs (IM3)
- Cooperative traffic management concept (TM1)
- Digitalise traffic rules and regulations (TM2)
- Improved information quality for automated vehicles (TI1)
- Standard communication protocols related to automated vehicles (TI2)
- Provision of hybrid C-ITS traffic information services (TI3)
- New infrastructure and regulations for traffic law enforcement (EN1)
- Environmental enforcement utilising geofencing and other tools (EN2)
- General physical road design changes (NR1)
- Harmonised management of road works sites (RW1)
- Awareness by automated freight vehicles of their own gross weight and individual axle loadings in order to determine ODD (new)

The actions above provide additional information related to the deployment highly automated vehicles, their function and evolution so that when the roll-out of highly automated vehicles is sufficient to warrant physical and digital infrastructure investments and changes in operational practices, the NRAs have the knowledge needed to make the related decisions and implementations. Some of the actions could commence and benefit immediately even human-operated vehicles, such as improving information quality or harmonised management and marking of incident and road works sites. The contents of such actions would likely be a bit different if the additional needs of highly automated vehicles are considered. Hence, these carry the "regret" element. However, at least some of the regret element can be mitigated by digitally enhanced learning and change detection mechanisms for instance via simulation capabilities in a Digital Twin environment. One tends to learn more if one is committed to doing something – even regrets or forms of mistakes or failures. Already some NRAs are following this path of "learning by doing". When trying to avoid any mistakes, some of a NRA's digital excellence might quickly move to organisations where mistakes are whole-heartedly accepted as they know that one learns quickly from mistakes. Consequently, a sustainable role model "study and learn" likely necessarily involves NRAs embracing some learning from errors and accompanying expectation management with the management and stakeholders.

The key actions for deployment contain the following:

- Optimal minimum risk manoeuvres and providing infrastructure for them (PI1)
- Digital twins for road transport system including ODD and ISAD information (DI4)
- Legal framework for driverless maintenance vehicles (MA1)

All of the three actions are recommended to commence urgently at least for some parts of them. Minimum risk manoeuvres (MRMs) are currently worked upon in standardisation with little or no NRA participation while MRMs will in fact have major impact on the planning and building of the physical road infrastructure with potentially huge investment consequences. Providing input and maintaining digital twins may turn out to be resource demanding, but the key aspects of the action are the specifications and requirements for ODDs and ISADs. These call for close dialogue between road operators and the automated vehicle industry stakeholders to clarify the requirements and expectations from both sides and to agree on a consensus solution. It is anticipated that close dialogue with vehicle industry stakeholders will continue to be a rather bumpy road – and might need accompanying expectation management within NRA-related stakeholders and top management. This is less a personal issue and more an issue of point of control in historically rather different silos. Finally, the driverless

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

maintenance vehicles are already being rolled out in the form of safety trailers and mowing robots, and a sound legal framework is a necessity for the road operators.

Most of the actions were labelled into the "study and learn" category. This implies the importance of research, pilots and large-scale demonstrations and pilot deployments in the short and medium term. In addition to national activities, the NRAs should actively participate in related Horizon Europe and Connecting Europe Facility actions for learning, networking and information sharing purposes. It is essential that CEDR should facilitate sharing of information and best practices, and openly discussing unanticipated challenges and early forms of failure.

NRAs need to consider whether they should participate in the international fora which are setting standards for automated driving systems (ADS), specifically UNECE WP.29. Otherwise they run the risk that automated vehicles will operate to the detriment of the operational goals of the NRAs.

Almost all of the actions need to be carried out with a number of different stakeholders. The stakeholders include, among others, OEMs, ADS providers, HD map providers, fleet operators and managers, road authorities and operators, cities, traffic management operators, research and innovation organisations, road planning, building and maintenance contractors, road and vehicle equipment providers, telecommunications industry, mobile network operators, police, rescue operators, transport safety agencies, ministries, the EC, and standardisation bodies. In stakeholder cooperation, CEDR has a major role in carrying out stakeholder discussion on a strategic executive level with related organisations representing the other stakeholders while NRAs carry out the cooperation and collaboration on the project and national, and tactical and operational levels.

With rather ambitious policy goals and challenging financial contexts, we can not choose between digitalisation, resilience, and greening Europe. All of these need to be accomplished. Some elements of digitalisation involve ecosystems and platform thinking with evolution path dependencies. Shutting down or minimising digitalisation forefront activities might quickly deprive NRAs from some of its current cooperation opportunities with different stakeholders.

The work has been carried out with the focus on the five use cases in highly automated driving selected in MANTRA. These use cases were highway autopilot including highway convoy, highly automated freight vehicles on open roads with platooning, commercial vehicles as taxi services (robot taxi), driverless safety trailers, and driverless winter maintenance vehicles. However, many of the issues were generic to all or most use cases of highly automated driving. Nevertheless, some other use cases could have resulted in a few additional actions to be considered for the recommended road map presented in this deliverable.

References

Abe, Katsuya (2019): The role of government for deploying connected and automated vehicle in Japan. Session AP04 - Automated driving of snowplows. 26th ITS World Conference 23.10.2019. Ministry of Land, Infrastructure, Transport and Tourism, Japan. Singapore, 2019.

ACEA (2019): Automated Driving. Roadmap for the deployment of automated driving in the European Union. 8 p. https://www.acea.be/publications/article/roadmap-for-the-deployment-of-automated-driving-in-the-european-union

ACEA (2020): Roads of the future for automated driving. ACEA Discussion paper. 17 p.

Aigner, Walter; Kulmala, Risto; Ulrich, Sandra (2019): Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040. MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business, Deliverable 2.1.

Arabzadeh, Ali; Notani, Mohammad Ali; Zadeh, Ayoub Kazemian; Nahvi, Ali; Sassani, Alireza; Ceylan, Halil (2019): Electrically conductive asphalt concrete: An alternative for automating the winter maintenance operations of transportation infrastructure. In Composites Part B: Engineering, p. 106985. DOI: 10.1016/j.compositesb.2019.106985.

AlixPartners (2020) AlixPartners survey shows muted willingness to pay more for autonomous vehicles and significant interest in giving up vehicle ownership for robotaxi ride-hailing. Press Release. January 2020. Available online at https://www.alixpartners.com/media-center/press-releases/global-autonomous-vehicle-study-2020/

Bladescanner (2019): RISKMON Anlageninspektion und Risk-Monitoring mit Hochleistungsdrohnen und Sensorik. Mobilität der Zukunft 2016. Available online at https://www2.ffg.at/verkehr/projekte.php?id=1538&lang=de&browse=programm,accessed on 17 January 2020.

Brockfeld, Elmar; Lorkowski, Stefan; Mieth, Peter; Wagner, Peter (2007): Benefits and limits of recent floating car data technology - an evaluation study. 11th World Conference on Transport Research. C2-830.

CCAM Partnership (2020). Strategic Research and Innovation Agenda. Proposed European Partnership under Horizon Europe CCAM Connected, Cooperative & Automated Mobilty. V0.9, 01/07/2020. 84 p.

CEDR (2011). Best practice in European traffic incident management. CEDR Task Group T13. March 2011. Conference of European Directors of Road CEDR. 84 p.

CEDR (2017). Description of Research Needs (DoRN). CEDR Transnational Road Research Programme Call 2017: Automation. CEDR Transnational Road Research Programme funded by Austria, Finland, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and the United Kingdom. November 2017.

Chan, C.-Y. (2017). Advancements, prospects, and impacts of automated driving systems. International Journal of Transportation Science and Technology, 2017. Available online at www.elsevier.com/locate/ijtstasdasd

CREDO (2017). Highways England – Roadworks Management. Final Report: Executive Summary. Prepared for ORR Office of Rail and Roads. 24th May 2017. 24 p.

C-ROADS (2019) https://www.c-roads.eu/platform.html. Accessed 15 March 2019.

DfT (2019). Lane Rental Schemes Guidance for English Local Highway Authorities. Department for Transport. July 2019. 24 p. Available online at

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819199/lane-rental-bidding-guidance.pdf

DTF (Ed.) (2019): Data for Road Safety. European Data Task Force. Available online at https://www.dataforroadsafety.eu/.

EC (2013): Commission Delegated Regulation (EU) No 886/2013 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users. No 886/2013. In *Official Journal of the European Union L 247/6-10,*. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0886&from=EN .

EC (2015): Commission Delegated Regulation (EU) No 2015/962 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the provision of EU-wide real-time traffic information services. No 962/2015. In *Official Journal of the European Union L 157/21-31,*. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R0962&from=EN, accessed on 1/17/2020.

EC (2017): C-ITS Platform Final report Phase II. Cooperative Intelligent Transport Systems Towards Cooperative, Connected and Automated Mobility. Available online at https://ec.europa.eu/transport/sites/transport/files/2017-09-c-its-platform-final-report.pdf, accessed on 26/7/2019.

EC (2019): Communication from the Commission - The European Green Deal. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0640&from=EN, accessed on 2/15/2020

EC (2020): A European strategy for data. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2020) 66 final. Brussels, 19.2.2020. 35 p. Available online at: https://ec.europa.eu/info/files/communication-european-strategy-data_en, accessed on 3 March 2020.

ERTRAC (2020). European Partnership under Horizon Europe Connected, Cooperative and Automated Mobility (CCAM). ERTRAC 13 April 2020. 54 p. https://www.ertrac.org/uploads/images/CCAM_Partnership_Proposal_13-04-2020.pdf

EU EIP (2017): Workshop report (15–16 March 2017, Utrecht): Facilitating Connected & Automated Driving – a Road Operator's Perspective. Version: 1.0 30.6. 2017, EU EIP.

EU EIP (2020): Reference Handbook for harmonized ITS Core Service Deployment in Deployment.

European Parliament (2015): Directive 2015/758 of the European Parliament and of the council of 29 April 2015 concerning type-approval requirements for the deployment of the eCall in-vehicle system based on the 112 service and amending Directive 2007/ 46/ EC.

European Parliament (2019): Directive (EU) 2019/520 of the European Parliament and of the council of 19 March 2019 on the interoperability of electronic road toll systems and facilitating cross-border exchange of information on the failure to pay road fees in the Union. EU Directive 2019/520.

FHWA (2010) 2010 Traffic Incident Management Handbook Update. Federal Highway Administration, Office of Transportation Operations. January 2010. 116 p. Available online at https://ops.fhwa.dot.gov/publications/fhwahop10050/fhwahop10050.pdf

FHWA (2015). Tabletop Exercise Instructions for Planned Events and Unplanned Incidents/Emergencies. U.S. Department of Transportation, Federal Highway Administration.

FHWA-HOP-15-004. 29 p. Available online at
https://ops.fhwa.dot.gov/publications/fhwahop15004/fhwahop15004.pdf

FHWA (2020). Work Zone Best Practices Guidebook. Department of Transportation, Federal Highway Administration. Available online at
 https://ops.fhwa.dot.gov/wz/practices/best/bestpractices.htm. [Accessed 12 February 2020]

Geels, Frank W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions 1 (2011) 24–40. Available online at doi: 10.1016/j.eist.2011.02.002

Haspel, Ulrich (2019): C2SBA und C2NBA. Aktueller Stand und Planungen. Bayerische Staatsbauverwaltung, Zentralstelle Verkehrsmanagement.

Highways Agency (2009). Network Management Manual Part 7 - Traffic Incident Management And Contingency Planning. Version 1 Amendment No 8. July 2009. 117 p.

IDSA (2020). International Data Spaces Association.
 https://www.internationaldataspaces.org/ . Accessed 9 July 2020.

Kaber, D. B., & Endsley, M. R. (1997). Out-of-the-Loop Performance Problems and the Use of Intermediate Levels of Automation for Improved Control System Functioning and Safety. Process Safety Progress, 16(3).

Kamalski, Theo; Rytkönen, Mika (2015): iMobility Forum SafeAPP WG. Presentation at the iMobility Forum Steering Group Meeting. ERTICO, 19/11/2015. 13 p.

Koskinen, J.; Kuusniemi, H.; Hyyppä, J.; Thombre, S.; Kirkko-Jaakkola, M. (2018): Positioning, location data and GNSS as solution for autonomous driving. Presentation made at I Aurora Summit, Olos 16-17 January 2018. Available online at https://vayla.fi/documents/20485/421308/Koskinen_Aurora_Summit.pdf/bf11703e-fc5a-4377-98ef-d784469e5be0, accessed on 1/17/2020.

Kulmala, Risto; Jääskeläinen, Juhani; Pakarinen, Seppo (2018): The Impact of Automated Transport on the Role, Operations and Costs of Road Operators and Authorities in Finland. EU-EIP Activity 4.2 Facilitating automated driving., p. 143. Available online at https://www.traficom.fi/sites/default/files/media/publication/EU_EIP_Impact_of_Automated_Transport_Finland_Traficom_6_2019.pdf.

Lee, Marc (2018). Mobility pricing in practice: A look at London, Stockholm and Singapore. Policynote Apr 30, 2018. https://www.policynote.ca/mobility-pricing-in-practice-a-look-at-london-stockholm-and-singapore/, accessed 20 February 2020.

Liao, Chen-Fu; Donath, Max; et al. (2018): Development of Driver Assistance Systems to Support Snowplow Operations. Test and Demonstration of Connected Vehicles Applications to Maintenance Operations. CTS18-14. With assistance of University of Minnesota.

Malone, Kerry; Schreuder, Max; Berkers, Frank; Helfert, Katharina; Radics, Lena; Boehm, Martin et al. (2019): Digitalisation and Automation. Implications for use cases, Identification of Stakeholders and Data Needs and Requirements. DIRIZON Deliverable Nr 3.1. Draft 1.0, October 2019. 68 p. https://32b45a2b-9547-4eca-9049-bd2192a42b0d.filesusr.com/ugd/1cba1b_4f8f241d96174509bdc0e6ccd13727d8.pdf

MAVEN (2020). EU project web site http://www.maven-its.eu/. Accessed 13 February 2020.

McKinsey (2020): The imperatives for automation success. McKinsey & Company Operations Practice. August 2020. 10 p.

next mobility news (2019): C2X-Kommunikation für einen effizienteren Winterdienst. Available online   at   https://www.next-mobility.news/c2x-kommunikation-fuer-einen-effizienteren-

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

winterdienst-a-872528/?cmp=nl-392&uuid=2A64A51F-61C9-46CA-A09B-4EAF0263493C, accessed 17 January 2020.

Niculescu, Mihai; Antola, Petri; Kulmala, Risto; Rausch, Jessica; Cheung, Stephanie; Schulz, Susanne; Amelink, Maarten; Rey, Laura; Barr, Jacqueline; Daura Albeldo, Xavier (2019): Autonomic functions implemented in existing ITS – status update 2019. Version 1.2, 11 October 2019. 56 p.

Niculescu, Mihai; Barr, Jacqueline; Leiro Garcia, Germa; Combi, Claudio; Cheung, Stephanie; Antola, Petri; Kulmala, Risto (2020): Needs for autonomic functions in road operators' ITS. Good and bad practices from increasing the automation of road operators' ITS – lessons learned. Update 2020. Version 0.3, 7 January 2020 2020. 46 p.

OECD/ITF. (2018). Safer Roads with Automated Vehicles? OECD/ITF. Available online at https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf, accessed 13 February 2020.

Pettersson, Jan; Resch, Stefan; Straten, Eric thor; Miettinen, Hanna-Mari; Limbach, Roman; Romaidou, Katerina et al. (2018): Trans-European Road Network, TEN-T (Roads) 2017 Performance Report. Edited by Conference of European Directors uf Roads (CEDR). Available online at https://www.cedr.eu/download/Publications/2018/TEN-T-Performance-report-2017.pdf, accessed on 1/17/2020.

PIARC (2020). Planning for Emergencies. Road Network Operations & Intelligent Transport Systems. A guide for practitioners. World Road Association PIARC. https://rno-its.piarc.org/en/network-operations-rno-activities-planning-and-reporting/emergency-plans Accessed 20 February 2020.

Queensland (2018). Event traffic management design guidelines. State of Queensland, Department of Transport and Main Roads. July 2018. 61 p.

Radics, Lena; Helfert, Katharina; Wegscheider, Sophie; Boehm, Martin; Schreuder, Max; Berkers, Frank; Lüpges, Christian; Tucker, Mark; Kakouris, Emmanouil (2020). Report on stakeholder responsibilities in the areas of data exchange, digital platform, and actions needed for making identified use cases reality. DIRIZON Deliverable Nr 4.1, June 2020. 174 p.

SFS (2020): A snapshot of the standardization of intelligent transport systems. Finnish Standards Association SFS 1/2020. 72 p.

SmartCitiesWorld news team (2020). Transport for London collaborates with Bosch on smart mobility https://www.smartcitiesworld.net/news/news/tfl-collaborates-with-bosch-on-smart-mobility-3950

SOCRATES 2.0 (Ed.) (2018): Proposed cooperation framework & bottlenecks. Activity 2 – deliverable, June 2018. Available online at https://socrates2.org/download_file/112/184, accessed on 13 February 2020.

SOCRATES 2.0 (Ed.) (2019). Setting the stage for the deployment of interactive traffic management. 44 p. Available online at https://socrates2.org/download_file/144/184, accessed on 13 February 2020.

Strand, Niklas; Zofka, Ewa; Ponweiser, Wolfgang; Lamb, Martin; Hedhli, Abdelmename; Adesiyun, Adewole (2020): Practical learnings from test sites and impact assessments. STAPLE Deliverable No 4.1 & 4.2 final version. 8 April 2020. 60 p. https://www.stapleproject.eu/ajax/DownloadHandlerFM.php/downloadFile?id=15394

TM2.0 (Ed.) (2018): Platform web site. Available online at http://tm20.org/, accessed on 13 February 2020.

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

Trafikverket (2015): Road Safety – Vision Zero on the move. The Swedish Transport Administration. Available online at https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/20151210_1_sweden.pdf accessed on 2/15/2020

TransAID (2020). EU project web site https://www.transaid.eu/. Accessed 13 February 2020.

van der Tuin, Marieke; Farah, Haneen; Correia, Gonçalo; Wadud, Zia; Carsten, Oliver; Ulrich, Sandra; Aigner, Walter (2020): Impacts of automation functions on NRA policy targets. MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business, Deliverable D3.2.

Ulrich, Sandra; Kulmala, Risto; Appel, Kristian; Aigner, Walter; Penttinen, Merja; Laitinen, Jukka (2020): Consequences of automation functions to infrastructure. MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business, Deliverable 4.2.

U.S. DOT (Ed.) (2018b): Preparing for the Future of Transportation. Automated Vehicles 3.0. Available online at https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf, accessed on 1/17/2020.

Verweij, Fred (2016). Cooperative ITS Corridor Rotterdam – Frankfurt/M – Vienna. Status in the Netherlands. Presentation for the Amsterdam Group, Amsterdam, 26 April 2016. 27 p.

Vreeswijk, Jaap (2019): Workshop report: constructs of the Operational Design Domain (ODD) of Automated Vehicles. ITS World Congress Singapore, 22.10.2019.

Weekley, Jill; Cornwell, Ian; Nitsche, Philippe (2017). CEDR Contractor Report 2017-04. Call 2013: Traffic Management METHOD, UNIETD and PRIMA projects. 30 p.

Zencic (Ed.) (2019): UK Connected and Automated Mobility Roadmap to 2030. Available online at https://zenzic.io/roadmap/, accessed on 1/17/2020.

Workshops

SDA platform and DG Connect: "5G deployment for Automated Mobility" workshop at 13th ITS European Congress, Eindhoven, June 2019

CEDR & MANTRA: "Impacts of highly automated driving on policy targets and infrastructure". Hosted by FFG in Vienna, 10 September 2019.

European Commission, "5G for connected and automated mobility", Digital Transport Days Helsinki 7 – 9 October, 2019

Aigner, Walter: January / February 2020: (bilateral discussions of Walter Aigner with experts from Deutsche Telecom, Telecom Italia Mobile, Swarco, several local road operators, Fiat Chrysler and BMW) in preparation of the DG Connect workshop February 13, 2020 Brussels and a joint workshop in preparation of transferring lessons learnt on European digital corridors to be held in October 2020).

European Commission, DG CNECT: "CAM challenges towards cross-border deployment", February 13, 2020 Brussels

CEDR & MANTRA: "Roadmap for Adaptation of NRA Core Business due to Highly Automated Driving". Hosted by FFG in Vienna, 13 March 2020.

Annex 1 Survey on priority actions

An internet survey was sent on Monday 6 April 2020 to more than 160 experts with the following instruction:

Dear expert,

I am sending you this message as we are recommending actions for the national road authorities in order to adapt their core business to highly automated driving in the next two decades. We have come up with a list of possible actions in 11 road authority business areas, but the list is very long (currently 92 actions), and the workshop that we organised for their prioritisation suffered from low participation as it coincided with the full outbreak of the covid-19 pandemic in Europe.

"We" means project MANTRA, funded by the CEDR (Conference of European Directors of Roads) Transnational Research Programme. Our partners and results can be found at the project website www.mantra-research.eu. We have specifically studied five different use cases of SAE Level 4 highly automated driving of 1) Highway autopilot, 2) Highly automated freight vehicles on open roads including platooning, 3) Robot taxis, 4) Driverless safety trailer for e.g. road works, and 5) Automated winter maintenance vehicles. We are especially looking at identifying and describing the actions needed in order for the road authorities and operators to adapt their core business in order to be able to facilitate and cope with highly automated driving on their road networks. More information on the roadmap and identification of actions can be found in MANTRA deliverable 5.1 (link to report).

Now we need your expertise and support in order to identify the key priority actions among the ones recommended. The full list of actions is given in seven lists in an online survey. The lists are organised in according to the road authority/operator core business areas of

- *Physical infrastructure (1 list, 10 actions)*
- *Digital infrastructure (1 list, 24 actions)*
- *Operations and services (4 lists, 42 actions)*
- *Planning, building, maintenance (1 list, 16 actions)*

We hope that you would now open the survey, and go through the lists in it. You can either go through all of the lists, or just focus on one or more lists according to your own expertise or interest. In each list, mark your priority action by clicking the box for the action. Note that you can give the priority to some of the actions only, the maximum number is given at the top of each list.

I predict that marking the priorities in the lists will take you between 5-15 minutes, depending on whether you go through only one, several or all of the lists. The time could increase by 5-20 minutes if you also wish to make comments or propose additional actions - this would need clicking "Yes" at the bottom of each survey page – click "No" if you were happy with the page in question and wish to move to next list.

We are extremely happy if you could also send this message/survey to other experts in your organisation or networks, who in your view have the relevant expertise in some of the road authority/operator core business areas.

The survey can be found at https://forms.gle/xxxxxxxxxxxxxxxxx

The deadline for responding to the survey is 30 April 2020.

On behalf of the MANTRA project, Risto Kulmala,   Coordinator of MANTRA

The survey results were accessed from the web storage on 7 May 2020. In all, there were 21 respondents from national road authorities or the relevant ministries (labelled below as NRAs) and 24 other respondents (Others). The number of priority nominations received are listed in the following seven tables.

The number of priorities were restricted to 3-5 per table, depending on the number of candidate actions. The respondents were instructed to score the priorities only to those business areas with which they were familiar, Thereby, some respondents did not give priorities in all areas. Furthermore, some respondents indicated less priorities than the maximum number for some business areas. For this reason, the total number of priority nominations given are listed at the bottom line of each table.

Yellow colour in the last two columns indicate the actions, where the priority nominations exceeded the threshold for the business area. The final actions selected for the action plan are indicated by colour in the first column – yellow for a priority action, light brown/orange for two-three actions combined in the business area to form one priority action, and green colour for an action combined to a priority action in another business area.

Physical infrastructure	Priority nominations	
Action	NRAs	Others
Uniform wear of pavement enabled by wheel path alteration in cross-section implemented by OEMs and ADS providers	3	3
Pavement design and maintenance standards review and adaption to mitigate increased rutting (in case of failure of action above)	6	1
Pavement monitoring and maintenance on truck platooning routes (depends on actions above)	1	1
Management of bridge loads in consideration of truck platooning	6	1
Additional emergency bays, wide shoulders and safe harbours to accommodate minimum risk manoeuvres for AVs	9	9
Safe minimum risk manoeuvre specification considering also cases of very large AV fleets	5	7
Safe passenger pick-up and drop-off + EV charging points for automated shuttles and robot taxis	5	6
Road markings of sufficient retro-reflectivity in different visibility and weather conditions	8	6
Road signs' machine readability and digital twins, including variable message signs	11	9
Road equipment such as gantries, gates, etc. to facilitate separation of AVs from other vehicles, and landmarks to facilitate accurate positioning of AVs	4	4
	58	45

MANTRA

Digital infrastructure	Priority nominations	
Action	**NRAs**	**Others**
HD map processes to ensure up-to-date map information to AVs	**10**	**11**
Provision of road network related data to HD maps	**8**	**5**
Maintenance of HD maps to keep their content up-to-date	**11**	**6**
Accountability in case of mistakes or conflicting interpretation (mistakes will occur)	**2**	**2**
Use digital technologies to leverage "shades of knowledge" / less documented yet emerging knowledge in NRAs	**1**	
Use digital technologies to dynamically identify yet emerging new frontiers / unknown unknowns related to AVs		
Cybersecurity issues for connected and highly automated vehicles	**15**	**13**
Find ways to cope with innovation risks (shorter innovation cycles in digital) (possibly in a commercial role model)		**1**
Update procurement policies (shorter innovation cycles) accepting that there are several technology options with unclear outcome / significant investment risk	**5**	**4**
Update procurement policies towards European digital platform-based ecosystems rather than stand-alone products and services	**2**	**1**
Provide RTK or corresponding land stations	**4**	**3**
Provisions in tunnels to ensure safety for AVs and mixed fleets	**3**	**4**
Trunk communications for short range and longer range V2I	~~**4**~~	~~**2**~~
Roadside stations for short range V2I	**5**	**4**
External indication of being driven by ADS, or being last in platoon to ensure safety and TM	**1**	**1**
Road operator fleet supervision centres	**5**	
Remote operation centres including questions of "roaming" / cooperation between operation centres		**3**
Use of digital twins for the (road) transport system including ODD and ISAD information	**6**	**6**
New role from digital twins spin-off not only for building and maintenance but explicitly for high intensity simulation and traffic flow operation	**1**	**1**
Mandate to provide existing data to HD Maps/digital twins	**3**	**2**
Mandate for fleet managers and OEMs to provide feedback on HD maps		
Strengthen absorptive capacity towards artificial intelligence, digitalisation and automated decision making (might involve a wide role for NRAs)	**2**	**4**
Human resources with digital expertise	**8**	**5**
Competitive awareness and potential selective cooperation with big tech companies who have already taken steps into the mobility domain and increase their roles in the digital mobility ecosystem,	**2**	**3**
	93	**81**

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

MANTRA

Incident, event and crisis management	Priority nominations	
Action	**NRAs**	**Others**
Harmonised marking of incident sites to be correctly recognised by AVs	8	7
Harmonised management of incident sites	4	~~5~~
AVs to provide information on incidents, e.g. by detecting stopped vehicles and roadway defects	10	10
Digitalisation of incident and traffic management plans	10	6
Automation of incident warning and rerouting services, e.g. for over-wide vehicles	1	4
Response to emergency vehicles	3	6
Use of safety trailers at incident sites to safeguard clearance	5	1
Use of safety trailers and similar to protect moving events	2	1
Provision of incident & event related data to traffic managers/ service providers	7	5
Prediction of incidents via AI	1	4
Legal adaptations to enable data sharing of safety critical data	6	7
Leading or coordinating role of NRAs & Ros in road incident management	3	3
	60	59

Traffic management and control	Priority nominations	
Action	**NRAs**	**Others**
Cooperative traffic management concept	15	7
Digitalisation of traffic management centres	13	8
Access control (slots) and/or pricing	1	5
Digitalise traffic rules and regulations	10	8
Deployment of geofencing for traffic management	6	3
Provision of ODD management	3	6
Conductor role of road authority/ operator in traffic management (as in incident management)	5	5
Real-time lane management	4	2
Removal of informative and route guidance road signs – relevant for all vehicles		
Flexible roadside stations		
Issues of human decision making at traffic management centres	~~1~~	~~2~~
New role: Traffic control room paradigm shift from safety-orientation to optional societal optimum risk management	2	4
	55	50

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads

MANTRA

Traffic information	Priority nominations	
Action	NRAs	Others
Standard AV-suitable comm protocols with TMC, fleet managers, service providers and AVs	7	9
Provision of hybrid C-ITS traffic information services	7	6
Enhancing traffic information content to serve highly automated vehicles	5	8
Improving information quality to serve highly automated vehicles	11	7
Quality assurance and assessment of data for AVs	7	6
Sharing of data and storage of data relevant for safety and traffic management (note: also relates to Enforcement)	7	8
Harmonisation of pictograms and messages (including messages in text)	7	4
Security of data (note: also relates to Enforcement)	8	6
	59	54

Enforcement and road user charging	Priority nominations	
Action	NRAs	Others
Enforcement		
New infrastructure and regulations for traffic law enforcement, including for conventional vehicles	13	11
Enforcement through weigh-in-motion systems	1	4
Tamper prevention	8	7
Environmental enforcement related to e.g. geofencing	6	8
Wrong way and tunnel driving detection and enforcement; routing enforcement	5	3
Road use charging		
Implementing of physical measures possibly required by highly automated vehicles on toll plazas		2
Marking of toll plazas for highly automated vehicles	2	1
Definition of a pricing policy for highly automated vehicles	2	4
Inclusion of road use charges into HD maps	2	1
Update of concession agreements	2	2
	41	43

MANTRA

New roads planning and building, maintenance, road works	Priority nominations	
Action	**NRAs**	**Others**
New roads planning and building		
General physical road design changes to accommodate highly and eventually fully automated vehicles	9	9
Physical road design changes for ramps and junctions to better accommodate highly automated vehicles among human operated vehicles	3	2
Road categorization ISAD levels also for digital and physical infrastructure	5	7
Provision of digital twin and digital data of new roads / road sections	5	4
Heavy maintenance planning		
Use of digital twin and digital data of new road for heavy maintenance planning	4	3
New approaches to road condition data collection for deterioration monitoring	5	5
Road works management and planning		
Standardized communication protocols with TMC, fleet managers, service providers and automated vehicles	7	4
Provision of hybrid C-ITS road works warnings	7	8
Harmonised marking of road works sites for correct recognition by AVs	5	5
Harmonised management of road works sites	6	1
Use of safety trailers at road works to ensure safety	4	1
Use of automated vehicles to monitor the performance of road works management	1	2
Road and winter maintenance		
Integration of operations management centre and traffic management centre	5	4
Connected road maintenance zones	4	1
Legal framework for specific use cases of driverless maintenance vehicles	7	4
Procurement of automated winter maintenance vehicles	2	3
	79	63

CEDR
Conférence Européenne
des Directeurs des Routes
Conference of European
Directors of Roads