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Digital Road for evolving Connected & Automated Driving

Stakeholder Engagement Report

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Stakeholder Engagement Report

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1. Introduction

The main aim of the DiREC project is developing a common framework to support National Road Authorities (NRAs) to provide better engagement with Original Equipment Manufacturers (OEM) and service providers, identify clearer responsibilities and liabilities, and include tools to calculate the costs and benefits of providing different levels of support to Connected and Automated Vehicles (CAVs).

Greater engagement and dialogue are key. By understanding the infrastructure and communications requirements of automated vehicles, and the challenges faced by CAVs in an operational environment, NRAs will be able to strategically plan their networks to support Connected and Automated Driving (CAD) and place themselves in a much stronger position to influence how traffic operates on the network.

A proactive approach to liaising with vehicle manufacturers and service providers will also promote NRA involvement in the services that are developing around digital mapping, localisation, navigation and traffic management. By aligning the digital strategies and plans of the NRAs with the requirements of OEMs and CAVs, and by giving direction to service providers, a common framework for CAD will help achieve major cost efficiencies and facilitate economic transformation. It will help optimise the delivery of infrastructure and communications systems on national road networks in support of CAD implementation whilst helping NRAs maintain their influence over CAD activity.

In order to facilitate productive interactions with various stakeholders involved with CAVs, WP1 within the DiREC project is dedicated to stakeholder engagement activities. This will ensure that input from different stakeholder categories will be collected and utilized for CAV-ready framework development.

1.1. Objectives

The overall objective of WP1 is to arrange and manage the stakeholder engagement activities across the project (e.g., between automotive OEMs, European NRAs, CEDR project stakeholders, telecommunication service providers, and other service providers). The main goals of this work package are managing the stakeholder consultation activities and documents according to the project timetable; supporting the DiREC project communication team with organization and management of the project workshops and required workshop material; coordinating, organising and documenting stakeholder interviews, workshops and stakeholder engagement activities; analysing the findings of stakeholder engagement activities; and providing the final report and deliverable related to stakeholder engagement activities.

It should be noted that in order to manage the risks of not being able to organize workshops and physical meetings with participants from multiple countries due to the COVID-19 restrictions, it was decided in one of the early project consortium meetings that most stakeholder engagement activities will be in the form of one-on-one online interviews. This will be elaborated upon in the section describing the stakeholder engagement approach.

1.2. Expected outcomes

The following outcomes were achieved through WP1 of the DiREC project.

- State of the art regarding interactions and collaborations between CAD stakeholders as well as good practices and challenges involved
- Supporting and complementing the findings of WP2 regarding review and evaluation of the current situation within the CAD ecosystem
- Establishing the infrastructure and procedures for stakeholder engagement as well as initiating the engagements with relevant CAD stakeholders (to be maintained and utilized throughout the project)
- Providing necessary information (regarding the state of the art), contacts and engagements required for establishing the DiREC project advisory group.

1.3. Stakeholder categories

For the DiREC project, a list of stakeholders at the initial stage has been identified. This includes:

- Road owner and operators (e.g., NRAs)
- Vehicle OEMs and associates
- Telecommunication service providers & associates
- Other service providers including 3rd party data providers, data standard organisations (e.g., BSI), and mobile app providers.

Managing engagement activities of each stakeholder category has been allocated to a separate partner within the DiREC project. In the following section, the general approach and procedure for stakeholder engagement activities within the DiREC project are described. In sections 3-6, the results of stakeholder engagement activities are described separately for each stakeholder category. Finally, the last section summarizes the findings of all stakeholder engagement activities.

2. DiREC stakeholder engagement method

In this section, the DiREC stakeholder engagement method is described. The method includes stakeholder engagement approach, stakeholder engagement procedure and actions regarding the establishment of DiREC project advisory group.

2.1. Stakeholder engagement approach

For engaging the potential stakeholders of the DiREC project, a continuous stakeholder engagement approach with a long term perspective was adopted. This approach includes the following steps.

- Creating a pool of potential stakeholders using all contacts available to all DiREC partners
- Grouping the potential stakeholders into stakeholder categories identified in DiREC
- Identifying the relevant stakeholders for each partner within DiREC based on the tasks they lead
- Making the initial contact with stakeholders
- Engaging them with DiREC via interviews and receiving their input on state of the art related to CAD stakeholder collaborations and interactions as well as other CAD topics considered by the DiREC project
- Keeping in touch with them by sending them DiREC project news and updates, and inviting them to DiREC project events
- Establishing the DiREC advisory group with a selection of stakeholders who possess strategic knowledge about CAD topics and are interested in being part of the advisory group.

The reason for adopting this approach was the fact that a large proportion of the WP1 budget was scheduled to be realized within the first few months of the project. However, input, guidance and knowledge of the stakeholders is needed throughout the project. Therefore, we decided to dedicate the efforts in the beginning of the project to establishing the infrastructure and the procedures required for continuous stakeholder engagement, and to utilize these throughout the project (with minimal budget) to benefit from it for the rest of the work packages. This way not only we engage relevant stakeholders with the DiREC project, but also use their knowledge (via interviews) to determine state-of-the-art related to CAD, use these findings for review and evaluation tasks within WP2 of DiREC, and keep in contact with stakeholders for receiving their output on our research throughout the DiREC project.

2.2. Stakeholder engagement procedure

Using the approach described above, we first created a database of contacts for potential stakeholders including information about their background, institution, and the type of role they have within their institution. The list (with personal information excluded to adhere to GDPR) is provided in

Appendix A***: Stakeholders list***

Then, we approached potential stakeholders using a pull procedure that started with the relevant DiREC partner in charge of each stakeholder category asking the contact holder listed in the stakeholders list to invite potential stakeholders in respective categories for an interview. After making the first contact via the contact person, who is known to the potential stakeholder, the relevant DiREC partner in charge of the stakeholder category (to which the potential stakeholder belongs) took over the communication and arranged and conducted interviews.

Regarding the interview questions, first, a pool of all relevant questions was created in collaboration with all DiREC partners. The questions were regarding the CAD state-of-the-art from the perspective of each stakeholder category as well as task-related technical questions from WP2 subtasks that could not be answered using the existing literature or required complementary information. These

questions were categorised based on the subject theme, related tasks and related stakeholder categories. Before each interview, the DiREC partner in charge of the interview filtered the question list based on relevant stakeholder and relevant tasks in hand to have a general list of relevant questions for the interview. Then these questions were used to create a semi-structured interview guide to be used for the interview. A sample of the questions list is provided in

Appendix B***: Interview questions list***

A brief description of the semi-structured interview procedure used is provided here. The five-step procedure suggested in (Kallio et al. 2016) was used to develop a semi-structured interview guide. The interview guide includes the introduction and explanation of the interview procedure to the interviewee, interview questions including the main themes and the follow up questions, which include both state of the art questions and task related questions relevant to WP2 subtasks, the information check list (to make sure all required information is collected during the interview), and the interview wrap up procedure. Detailed description of the semi-structured interview guide can be found in

Appendix C***: Stakeholder interview procedure***

After conducting the interviews, interview transcripts and summary information of the interviews were created by the partner in charge of the interview. The interviewee's approval of the content and the information documented were obtained after each interview. Finally, the results were structured in a clear and informative format to be included in this report (sections 3-6).

2.3. DiREC project advisory group

The purpose of the DiREC Advisory Group will be to support the work during project lifecycle. The Advisory Group can of course extend beyond the end of the project. It will:

1. Provide guidance, vision and oversight for the DiREC project
2. Develop and refine a common agenda including identification of problems, goals and guiding principles
3. Provide consultancy on strategic level issues
4. Provide a dialogue between the NRAs with their partners and other important organisations.

As a result of WP1 activities, the DiREC Advisory Group will be established, which will include experts at the strategic level, to oversee the research and to provide high-level advice. The initial list of the candidate members for the advisory group was drafted while writing the DiREC project proposal. In addition, after each stakeholder interview, we asked the interviewed stakeholder if they are interested in receiving news related to the DiREC project and participate in DiREC future events. The next step is to ask interested stakeholders to join the DiREC advisory group. The vision and mission of the advisory group as well as expected commitment from the members and frequency of meetings is being defined by the DiREC technical lead in collaboration with WP leaders. The advisory group is expected to be established shortly after this information is finalised. The first DiREC project event with the advisory group will be held after completion of WP1 and WP2 and will include presenting the stage findings of all DiREC work packages and receiving high-level input from the advisory group.

The following sections include the results of our stakeholder interviews. The views expressed in the following sections are the views of the specific stakeholders interviewed. They do not reflect the views of the DiREC project partners or sponsors, nor do they represent the views of the entire industry. They should be seen as views of a sample of representatives from each stakeholder category.

3. NRA engagements

This section summarises our engagement with National Road Authorities (NRAs) with regards to their current support of CAD, their key challenges and their expectations.

One of the overriding issues that came up in interviews with NRAs was uncertainty: uncertainty over future legislation around CAVs, the likely levels of CAVS on the network, and the technical capabilities of CAVs both now and in the future. These uncertainties make it difficult for NRAs to plan and prioritise future support for CAVs, and to understand and define their roles and responsibilities, let alone try to allocate budgets.

NRAs operate on relatively long planning and budgeting cycles. Typically they look to have strategies and plans for the next 20 years, and to budget for investments over the next 5 years or so. However, CAV technologies and CAV uptake can and do move very quickly, faster than the typical planning and budgeting cycles of NRAs.

NRAs are also taxpayer funded. They are required to ensure that investment be inclusive and be seen to benefit all road users, not only owners and operators of advanced vehicles and advanced vehicle systems. Any investment should be validated and should have a definable benefit; however the above uncertainties make it difficult to calculate or estimate what those benefits might be.

There are of course many research and pilot projects operating across Europe which involve NRAs. NRA engagement with those research and piloting efforts to a large extent depends on how much resources they are prepared to commit. Some NRAs are in the very early stages of research, while others are progressing with full-fledged trials of various use cases on their networks.

NRAs are very aware of their responsibilities for road safety on their networks, and they need to ensure that introduction of CAVs does not increase safety risks for all road users. NRAs are therefore actively engaged their roles and responsibilities with regards to traffic management, and several are conducting research on the speed implications of CAVs and how they might respond.

With regards to physical infrastructure, there is a general feeling that NRA road infrastructure is of high quality, that fundamentally CAVs are designed for current infrastructure and therefore don’t need additional physical infrastructure or improved operational or maintenance practices to support them. To some extent there is an assumption that the best way to support CAVs would be through digitising traffic regulations, or digitising signage data, rather than physical or operational improvements. These attitudes are based on assumptions of current and future vehicle technologies.

Many of the research and pilot projects have therefore been about the technology and the C-ITS services to support autonomous driving, rather than the road infrastructure. In some countries there has been a lot of time and effort spent on engaging with the telecoms suppliers on cellular services and telecoms infrastructure, and the legislation, protocols, policies and risks associated with that (e.g. legislation around rights of access of telecoms providers to the roadside, how that relates to telecom provider targets to provide cellular coverage across the country, protocols and risks around installation of telecoms infrastructure on the road reserve, risks associated with 3rd party installers, access to the telecoms infrastructure for maintenance etc.). Other countries have been forging ahead in defining and developing C-ITS use cases, testing connectivity and messaging applications.

3.1. Interactions with other stakeholders

3.1.1. Required Interactions

Interactions with Government

There is a great need for government to bring relevant stakeholders together, to define roles and responsibilities. There is a need for interaction among the NRAs and OEMs through appropriate official forums – both nationally and European-wide. Most countries have national forums where stakeholders (including NRAs, OEMs and technology providers) present and share their work. However, in some countries, such forums are just to share information voluntarily, and not all OEMs are necessarily engaged or will engage unless there is legislation to require membership and to meet certain standards or benchmarks. In the most successful projects, national transport regulators are also involved, through coordinating, participating and supporting the project.

With regards to any legislation on allowing autonomous vehicles to use public roads, NRAs should be involved from the start, to identify the impacts and costs of potential solutions before any decisions are made before any legislation gets passed. This will allow NRAs to better plan and save money in the long run, rather than being reactive and playing catch-up to OEMs that have been working and lobbying in these areas for 10+ years.

Early engagement would also allow NRAs time clearly to define their responsibilities and adjust their organisations appropriately to better plan and manage their support. NRAs can be like 'oil tankers' in that they can take a long time to change direction. If there is a gradual evolution of CAV services, and gradual uptake of CAVs, then it will be possible to provide support, but if there is a sudden surge in CAV uptake and public outcry as to why they can't use full vehicle functionality, then it becomes more problematic for NRAs. Therefore, more interaction with OEMs and government is necessary to plan for the future.

Interactions with wider society

Car manufactures are providing technology that allows vehicles to drive autonomously or with various autonomous functions. However, the ability of people to legally use such functionality on the road network might be very limited for any number of reasons (such as lack of cell phone coverage, indistinct or confusing road markings, lack of standards on data exchange). It is going to be difficult to explain to the public why those limitations exist and why they can't use the functionality in their vehicles. The public will likely blame the network provider rather than the car manufacturer, and the trust and acceptability of CAVs may deteriorate.

NRAs are trying to look ahead, to determine what the impacts might be on their networks in future, and then work with other parties to see how best to address them. But there is a significant public conversation that needs to be had too, not only about functionality and what to expect, but the potentially significant levels of public investment that might be required to support what is essentially a technology that private industry is introducing.

Another potential issue is that fully autonomous vehicles might increase vehicle travel at the expense of other options. For example, people choosing to take pods rather than active travel options such as walking or cycling, or business people working in autonomous vehicles while traveling, could be detrimental to sustainable transport goals.

Therefore there are many potential implications across society that need to be researched and understood, and NRAs need to be more involved in these types of conversation.

Interactions with Local Authorities

There is a need for Local Authority involvement in national and European-wide forums. At present, most local authorities are not thinking about potential support to CAVs, they do not have dedicated funds for CAV research, and certainly do not have dedicated CAV teams. The level of road infrastructure and services are very different across all the levels of road network, and early involvement is key.

Car Manufacturers

Some NRAs feel that they are under-researched with regard to current technologies and future technology direction with CAVs, and there is not enough engagement with OEMs to understand how NRAs can support them.

Some NRAs believe that vehicle systems are designed to operate on current road infrastructure and, while there may be a case for minor adjustment/modification and improvement of existing infrastructure to better accommodate CAVs, the needs and priorities are not clear. There is also a feeling that future vehicle or C-ITS technology could make road infrastructure adaptation obsolete, and therefore there would be little point in investing in physical infrastructure support in the meantime.

There may be opportunities for modification with regards to width of road markings and reflectivity of paints, but further research is needed. We believe that there is still time to review any design standards and operational practices to help prepare for higher levels of autonomous driving.

There are, however, some projects with good interactions with car manufacturers and mobile network operators. C-Roads is a good example where roads agencies, mobile network operators, and car OEMs are all partners in projects in cross-border C-ITS scenarios. The project provides the forum for discussion and resolution of issues in a collaborative approach. The projects are used to pilot technology and to help participating NRAs understand the requirements and the business processes behind them, including coverage and latency requirements for different C-ITS applications.

Interactions with telecoms providers

Some NRAs are very much involved in discussions with their telco industry regarding roles and responsibilities for investments as well as maintenance of digital infrastructure for transport. However, others are still in the very early stages of these interactions.

Some NRAs report issues around provision of cellular communications, citing fundamental legislative, policy and operational issues around giving telecom providers access to private land for installation and maintenance of telecoms equipment. These include issues around legislation of rights of access of telecoms providers to the roadside, how that relates to telecom provider targets to provide cellular coverage across the country, protocols and risks around installation of telecoms infrastructure on the road reserve, risks associated with 3rd party installers, and access to the telecoms infrastructure for maintenance.

Interactions with 3rd Party Data Providers

Priorities of NRAs appear to be around existing traffic information services – e.g. the same data that is currently pushed to variable messaging signs and gantries such as lane closures, speed limits, roadworks, stopped vehicles – and making sure it's available to the vehicles in the locality that need it. Many NRAs are working to supply data to 3rd party providers who are establishing databases including ODDs to provide data to OEMs.

Other NRAs have worked with 3rd party providers to establish C-ITS platforms to communicate traffic management information to vehicles through local servers and roadside devices. C-ITS functions are evolving rapidly, and flexible architectures are necessary to accommodate future change.

It was noted that it is often quite difficult to identify what mapping data and/or mapping version is being used in an individual vehicle and to identify who supplied that data. This could have implications for road safety and liability going forward.

Internal NRA Business Areas

An NRA is a complex organisation in its own right. There are a number of different business units within the NRA organisation that need to be involved in understanding and supporting CAD, including business units such as standards, strategic planning, asset management, operations, maintenance, and projects. The roles and responsibilities of each – and their internal and external interfaces - with regards to providing support to CAVs are still being established and will continue to evolve.

CAVs will fundamentally change how NRAs operate in future, and they will need time to do that. NRAs can sometimes take a long time to change.

3.1.2. Effective interactions and collaborations

The Drive Sweden strategic innovation program has 200+ members from **all over the world**, driving the development towards sustainable mobility solutions for people and goods. Its intent is to develop and demonstrate efficient, connected and automated transport systems that are sustainable, accessible and safe for all. There are several thematic areas including public engagement, society planning, business models, digital infrastructure and policy development. The Swedish Transport Administration is actively leading the digital infrastructure thematic area to see how connectivity can support autonomous driving.

3.1.3. Areas in which collaboration should be improved

There are often many potential technological solutions to the same problem. It will require coordination and cooperation and direction to establish the best and most cost-effective solutions in any one situation or use case. One of the challenges around C-ITS is to define who are the actors and what are their responsibilities. Within ODDs, each actor should follow well-established rules of cooperation in relation.

3.2. Challenges

3.2.1. C-ITS

One of the challenges around C-ITS is defining who the actors are and what their responsibilities should be. Clearly, these actors include the vehicle, the road operator, the OEMs, and 3rd party providers such as TomTom or Waze or other V2V platforms. Within the ODDs, well-established responsibilities and rules of cooperation need to be defined. The responsibilities of each actor also help determine the technology requirements and the protocols.

So, for example, if a car crashes in a remote area, that can be broadcast to other vehicles without the need for infrastructure provided by the NRA. But for other use cases, such as coordinated overtaking, then that communication needs to be local. A vehicle can rely on other vehicles to provide the relevant information, or it can rely on the road operator to provide it. Highly detailed manoeuvres might be strictly V2V, but the road operator can provide the I2V context for that. If there are hundreds or thousands of vehicles trying to avoid each other, then that should be V2V, but in terms of providing optimised speeds for synchronised flow, or identification of incidents or weather conditions, then the infrastructure manager role becomes crucial.

There are many use cases to be considered, and different solutions may have to be applied in different environments (e.g. in high-traffic urban areas with good connectivity NRAs could consider I2V traffic management solutions to optimise speed and flow, versus low-traffic remote areas with connectivity challenges where V2V might be more effective and efficient). Another example is platooning, which can be strictly V2V, but there are cases where the infrastructure manager might need to become involved, e.g. to force the platoon to split at a crossing, or to instruct the platoon to move into the centre lane near exits or access points.

C-Roads is successfully working with the vehicle manufacturers and the European platforms, and participating in working groups and task forces, through various projects to work out the protocols and rules for each of these situations, and devising technical solutions to each. It is also prompting revisiting traffic management centre processes.

Other use-cases are also under consideration. Blue light vehicles may send out awareness messages saying “I’m here, heading in this direction, my sirens are on” which is clearly V2V communication (or V2I if the road operator is also listening). But there are other specific uses cases for example a cluster of emergency vehicles indicating that some sort of emergency operation is going on, and the road operator may look to support these cases through other V2I applications. There are differences around Europe too. In Austria, for example, some road operator vehicles can have blue lights to operate as emergency vehicles. Amber light vehicles might include tow trucks, operator vehicles or assist vehicles, perhaps also slow-moving or large format vehicles. Projects are still in the early stages of defining or identifying ways in which I2V applications can support particular use cases.

On the other hand, some NRAs believe that the starting point is that the intelligence should be in the vehicles, and not in the road infrastructure or communications infrastructure. If the communications infrastructure were to malfunction, for example, then it could jeopardise the whole system, even for those vehicles which are not autonomous or connected. Therefore they are keen to keep the road system as flexible as possible, and are not keen on the installation of lots of communications equipment or services that cater for a relatively small proportion of the vehicles on the network. These NRAs also believe that the uptake of autonomous vehicles (or rather autonomous functions) will be slow, and therefore they are not looking to prioritise any additional support for those. It is widely recognised through that there are special locations such as tunnels or bridges where connectivity is not likely to be adequate for certain processes, and that additional communications infrastructure will be required.

C-ITS services and systems are evolving rapidly. Second-generation C-ITS systems are now available which are scalable and provide different ways of implementing the same functionality, through for example ‘edge nodes’ which may be deployed in mobile edge computers, closer to the vehicles giving reduced latencies. Second-generation systems provide automated communication from the traffic management system to the vehicle. They will also support higher level automated functions such as overtaking and lane merging in future, through a mix of AI and human-driven traffic management interventions.

3.2.2. Multiple Environments and Multiple Solutions

Most national networks have a mix of different types of roads providing different levels of service, including high performance roads and other networks. Current focus with regards to CAD and C-ITS is on high performance roads and suburban areas. Those roads typically have sensors and loop detectors for traffic detection and counting, feeding through to variable messaging signs and to C-ITS services which communicate with CAVs.

Much of the focus of NRAs at present with respect to CAD is on connected vehicles. However some projects are implementing additional services to support high levels of automation from the point at which the vehicle enters the highway until the point at which it exits. Some European projects are intending to provide full connectivity and C-ITS services for up to 100 km in length. In some suburban settings, redundancy is being built into the communications infrastructure, including hybrid communications through IP networks to give full coverage of our infrastructure. This will allow NRAs to retrofit non-connected vehicles into connected vehicles through devices like TomTom or personal mobile devices. The vision is not to have different services, to but to have the exact same services available through IP networks, which could allow different strategies for deployment across parts of the network with heavy traffic, and those parts of the network with lighter traffic.

3.2.3. Data Sharing

At present, the priority of NRAS is to focus on datasets based on societal impacts such as traffic safety and the environment. NRAs in general are not investing in HD Mapping or Digital Twins, although they can supply data for 3rd party suppliers who want to create HD mapping or digital twin platforms. Liability issues are of concern to some NRAs over potential provision of incorrect or out-of-date mapping data. There are some applications of Digital Twins for simulation modelling of traffic flows under various scenarios of CAVs and percentage of CAVs on the network, to identify potential safety implications of mixed traffic situations.

With regards to data from CAVs being made available to the NRA. NRAs are currently focused on what has been legislated for already around safety related information, however that information isn't readily available from OEMs at the moment, NRAs have to go out and obtain that data through 3rd party providers. The proposed EU Data Act is intended to advance the exchange of data between businesses and from companies to the public sector, and will be analysed in the context of CAV later in this project.

NRAs in general are aware of the different types of operational data and data on the state of assets that could be obtained from CAVs (such as potholes, road condition). In some NRAs it is still very early days, and the processes on how they can use such data, and the benefits, still need to be worked out. In others, demonstrator projects are running where fleets of 3,000 connected vehicles communicate anonymised V2I data such as road friction, air temperature, and positioning; and this is combined with fixed sensor data to give comprehensive snapshots of road conditions during winter. Other applications mentioned included identification of locations where connected vehicles are running with their headlights on which potentially identifies locations where there is fog on the network. In this way, near-real-time information network can be accessed by NRAs without the need to install sensors.

It was noted that there are currently no incentives on OEMs to provide such information to NRAs, other than through cooperative demonstration or pilot projects.

3.3. Potential solutions to address the challenges

To be discussed.

3.4. Summary of key findings

There is a lot of uncertainty about future uptake of CAVs and future travel demand. This impacts budgeting and planning, and in general causes uncertainty about whether NRAs should support CAD, and the type of support that they should consider. Uptake of CAVs is likely to be driven by legislation. Once the legislation is in place, then trust and acceptability are likely to increase, and people's behaviours will likely change quickly. Future projections of CAVs on the network, and usage of those CAVs, will impact the business case for NRA support to CAVs. It is also important to understand that NRAs are funded by the taxpayer, and in general investment should be inclusive, and should be seen to benefit all road users. One particular example of that is NRA focus on traffic management and controlling speeds on the network as a whole to improve safety and efficiency.

There is a need for a collective international NRA approach to say, "These are the levels of service we can provide, and this is how much it is going to cost, and this is how long it will take us to implement on our networks". However, to date, there has been insufficient engagement between NRAs, OEMs and telecoms providers on the current and future capabilities of vehicle systems. Early engagement and understanding are necessary for NRAs to articulate their objectives, strategies, identify roles and responsibilities, and to plan and budget to support CAVs. Roles and responsibilities of NRAs in the areas of physical and digital infrastructure and services are still evolving. There will also be different requirements and different priorities within the strategic road network of a country, and many NRAs are only now beginning to define their objectives, and to define and plan for what those levels of support might be.

CAVs will likely have significant implications for usage and speeds, especially in mixed vehicle environments, and NRAs should have a clear position on how to respond via traffic management.

There are often many potential technological solutions to the same problem. It will require coordination and cooperation and direction to establish the best and most cost-effective solutions in any one situation or use case. One of the challenges around C-ITS is to define who are the actors and what are their responsibilities. Within ODDs, each actor should follow well-established rules of cooperation in relation.

It is clear from discussions with NRAs and from review of literature that there are many different NRA attitudes across Europe, and many potential solutions to the same problem depending on those attitudes and approaches. For example, one country might be willing to invest heavily in standardisation and maintenance of physical road signs, whereas other NRAs might consider that it is up to the OEMs to recognise existing signages, while others might say that rather than improving physical signs then they will invest in making digital sign information available to CAVs.

Another example is platooning on bridges. Some NRAs have an attitude that as long as they make information on load capacity of their bridges available, and if the load capacity of a bridge is not sufficient to support platooning, then the trucks should increase the distance in the platoon. Therefore they are not looking to design of infrastructure to accommodate platooning, rather they are looking at C-ITS and traffic management solutions. The same arguments can apply to almost all physical, digital and communications infrastructure and services.

4. OEM engagements

In this section, we provide a summary of the findings of our interviews with OEM experts regarding the state of the art within the CAD ecosystem and challenges ahead with taking CAVs to the next level. In order to put things in perspective, we start the discussion by describing the capabilities and automation levels of OEMs' current vehicles.

The first important observation from the expert interviews with OEM representatives and experts was that they do not always consider the automation functions in terms of SAE levels, even though they are aware of SAE classifications. On one hand, most OEMs are working on Advanced Driver Assistance Systems (ADAS) functionalities, which could be classified as SAE L1 and L2, and are currently available on commercial vehicles. On the other hand, they are developing automated driving systems (ADS), mostly on development vehicles, which could deliver supervised automation (SAE L2+, L3), and in some cases, unsupervised automation (SAE L4) within a very limited ODD (ODD is defined by geographical, weather and traffic variables). Of course, all the vehicles now must be supervised by a safety driver. In case of companies that develop software and algorithms for ADAS or ADS functionalities, such as environment perception, these functionalities could be used in all automation levels, but of course currently they are used in existing (development) vehicles.

Regarding the transition to the next level of automation, there was a consensus that rather than a leap to the next level, there will be a gradual evolution from supervised (hands-off, eyes-on) automation with many necessary driver interventions in a very limited ODD to a more and more extended ODD with fewer driver intervention until eventually having unsupervised automation in a very extended ODD. And this process could a take a long time.

The most suitable places and general use cases for starting with L3 and L4 automation, but interestingly also for connectivity, were considered to be robo-taxis in very limited geographical areas, industrial use cases such as vehicles in mining and large logistics sites, and semi-public places such as university campuses and airports due to the controlled environment. For consumer vehicles, highway automation was considered the best place to start. Highway automation from on-ramp to off-ramp with a reasonable speed in unsupervised mode seems to be a desirable and achievable target for the end of the current decade. However, large-scale success of automation in consumer vehicles would depend on having a relatively extended ODD.

4.1. Interactions within the CAD ecosystem

In this section, we describe OEMs' interactions with different CAV stakeholders. In order to determine all required and useful interactions, we asked experts about interactions, collaborations and data exchanges with different stakeholders that are necessary for them in order to deliver their main product or service as well as those interactions that are not necessary or in place at the moment but could deliver benefits. Next, in order to describe the CAV ecosystem from an OEM's perspective, we asked about interactions that are useful and productive as well as the ones that face challenges. All these interactions are described separately in the following parts.

4.1.1. Current situation: existing interactions and collaborations

It is essential to consider that most OEMs believe the vehicle should solely rely on the information available directly from the vehicle itself for automated driving (e.g., camera, sensors, and ADS software). Therefore, opting for autonomy rather than connectivity is a conscious and strategic choice made by most OEMs at the moment based on the extent and accuracy of the information available from other sources and the current connectivity infrastructure. This means many ADS software are solely or heavily vision-based at the moment. Nevertheless, as described below, (at least) a minimal level of connectivity is required for any ADS. Moreover, even cameras and sensors are provided by tier 1 suppliers, not the OEMs themselves. Therefore, full autonomy is almost never a possibility.

Below, we describe the main requirements for CAVs and discuss different sources of information as well as interactions and collaborations required for each. This will yield the existing interactions and collaborations among various CAD stakeholders.

4.1.1.1. Sensors and cameras

CAVs rely on sensors and cameras for positioning and environment perception. These sensors and cameras are usually provided by tier-1 suppliers. There is no major challenge for interactions between OEMs and tier 1s; however, sensor accuracy, reliability and cost are not at a desirable level for OEMs to take CAVs to the next level yet. Although performance of sensors and cameras is improving in time and at the same time, they are becoming more affordable, installing enough sensors and cameras to provide the desired level of redundancy in case of failures still imposes a high cost. Furthermore, existing sensors still have false-positive rates (detecting none-existing objects) that are too high for reliable L4 ADSs.

4.1.1.2. ADS software and algorithms

Automated driving system (ADS) is the combination of hardware and software that performs the dynamic driving tasks, including lateral and longitudinal control as well as object and event detection and response. It relies on artificial intelligence (AI) algorithms for its performance. Therefore, AI capabilities in terms of object (e.g., lane marking, traffic sign) and event (e.g., pedestrian crossing) detection, localisation and environment perception, trajectory planning, and longitudinal and lateral control are crucial for its performance. Most OEMs develop their own ADS software, but some use software or/and algorithms developed by other companies who provide such software. In some cases, the company who develops the ADS is owned by the OEM and in some others, the relationship is close to a tier 1 and an OEM relationship. In all cases, the OEM has a tight grip on the ADS software. Therefore, the collaborations and interactions are effective.

4.1.1.3. HD maps

HD maps can provide very accurate, 3D, and attribute-rich information about the road and the environment. Although they have been improved in recent years and some OEMs use them in their vehicles, since the existing maps do not offer the same level of accuracy and reliability in different places, most OEMs do not heavily rely on them at the moment. These maps are usually provided by third party service providers (e.g., TomTom), which means some interaction and collaboration between the OEM and the service provider as well as NRAs is necessary. These interactions will be discussed in detail later in this report.

4.1.1.4. Traffic information

There are two types of traffic information that OEMs can use; the first type is related to traffic state.

This information could be provided by road authorities, third party traffic service providers, or HD map providers (in collaboration with other parties mentioned). This type of information is currently available with a reasonable accuracy from third party traffic service providers. Yet this information could be improved through collaborations with road authorities as well.

The second type of traffic information that OEMs can use is digital traffic information (e.g., traffic rules, speed limits, variable message signs, etc.). Although this information is already integrated into maps at a very basic level (e.g., speed limits), and is helpful, current information is not at the level of detail that the ADS can actually rely on for traffic rules. Some NRAs are planning to provide such information to third party service providers to make available for CAVs; however, scalability of such information requires collaboration of many road authorities, which is challenging. Therefore, OEMs do not heavily rely on such information.

4.1.1.5. Legislation and standardisation

Another obvious must for successful deployment of CAVs is clear and favourable legislations and standards to clearly define responsibilities for each actor within the CAD ecosystem. For instance, as it stands in Germany, L3 automation is only allowed at speeds below 60 km/h, which practically means it can only be used for traffic jams. Such rules will hinder commercial success and large-scale deployment of CAVs. Another crucial issue is standardisation, particularly regarding safety of automated driving systems. Legislation and standardisation for CAVs requires close collaboration of OEMs, NRAs, third party service providers and standardisation organisations. These collaborations for legislation and standardisation seem to be among the most challenging issues for successful deployment of CAVs.

4.1.1.6. Connectivity

Although real-time V2X connectivity is not available on commercial vehicles now and OEMs are not planning to rely on it (at least in the near future), some level of (none-real-time) connectivity is required for basic functionality of ADSs. First, ADS software needs to be updated regularly. This is usually done via existing cellular networks (3G, 4G). Second, OEMs gather ADS performance data by probing data from CAVs. This is also usually done via existing cellular networks. This data can be used for improving AI algorithms used in ADSs, field learning, proof of safety and improving HD maps. Some OEMs are trying to encourage the use of Wi-Fi as well in places such as supercharging stations and personal garages to reduce connectivity cost.

Some OEMs (e.g., Mercedes and Volvo) have basic procedures for sharing emergency messages within the vehicles of the same fleet (via cellular networks), but due to low market penetration rate of vehicles equipped with such systems and the scarcity of the events triggering such messages, this type of communication is almost negligible at the moment.

Another type of (technically) existing connectivity is among the vehicles that use the same HD map. When a vehicle shares information such as location of accidents or temporary road closure with HD map provider, this information is uploaded to the map and can be used by other vehicles using the same map. So technically this is a form of connectivity that is currently in use. However, the information sharing (about the specific type of events mentioned) is neither frequent nor real-time.

Moreover, this procedure is not in place with all OEMs.

4.1.1.7. Weather information

Accurate and current information about weather conditions is required to constrain the ODD based on weather conditions. This requires some interactions between OEMs (or map providers if the weather information is provided by the map) and meteorology institutions or weather service providers. But there is no real challenge in these collaborations due to the simplicity of the business interactions involved.

4.1.2. Taking CAVs to the next level

In this section, we describe elements that are currently unavailable or available but not at the required quality but can deliver benefits for successful deployment of CAVs once (and if) they become available. This is a list of “nice to have” items to take CAVs to the next level. First, we describe each item, and then, we discuss what kind of collaborations, interactions and exchanges among CAD stakeholders are necessary to make the item available for CAVs.

4.1.2.1. Better physical infrastructure

There is a consensus among OEM representatives that general quality of infrastructure and more suitable infrastructure for CAVs can facilitate successful deployment of CAD. A comprehensive list of improvements and additions that can make the infrastructure more suitable for CAVs is provided in DiREC deliverable D2.1 but the most important items according to our interviews are harmonised traffic signs and lights, standardised location of traffic lights, machine-readable traffic sings and lane markings, well-designed on and off ramps, barriers in highspeed roads with two-way traffic, and good curvature of roads.

Another important topic mentioned by OEMs is road infrastructure design with CAVs in mind. Apart from retrospectively adjusting the existing infrastructure, new infrastructure could be designed and built with CAVs in mind. Examples of such measures include machine-readable signs (for instance using QR-codes on signs), and lane markings (for instance by checking with experts to make sure the colour, texture and contrast between markings and asphalt are ideal for ADSs).

In order to determine the details of quality improvements and adjustments on infrastructure elements, some level of collaboration between NRAs and OEMs is necessary.

4.1.2.2. Better HD maps

HD maps were recognised by most OEM representatives interviewed as one of the most important enablers for successful deployment of CAVs. Although most CAVs use some form of HD map, most OEMs do not heavily rely on HD maps, at least not in all terrains. The reason is the current level of accuracy and reliability of information provided by existing HD maps. Although HD maps have enjoyed rapid and significant improvements in their quality and accuracy in recent year, they do not offer the same level of accuracy in all parts of road networks in all countries and regions. This means CAVs must be capable of handling situations without maps, which requires not relying on HD maps for the core functionalities of ADSs. Moreover, since both static and dynamic attributes of roads change in time (e.g., road works and accidents), these maps require constant maintenance to stay up to date. There are current and evolving quality s for HD maps (e.g., ASIL and ADASIS) but the existing maps do not meet these standards at a desirable level for CAVs in a reasonably extended scope.

Information from CAVs' sensors and perception systems can be used to improve HD maps. Usually when OEMs sign a contract to use HD maps provided by a certain service provider, they agree to sharing certain information with the map provider that can improve the maps, and this information is indirectly shared with other vehicles that use the same map. This means some level of data sharing (within the fleet) is facilitated by the map provider. And if the map provider provides maps for multiple OEMs, all vehicles using the maps from different OEMs will have access to all data provided by the map. Given the fact that there are not many map providers, different OEMs using the same map provider is to extent inevitable. However, sharing map data among competing map providers is not likely to be materialised.

Apart from CAVs sharing data with maps, another potential collaboration that could improve the quality and accuracy of the information on HD maps is collaboration between map providers and NRAs. Both static and dynamic information provided by HD maps can be improved using information that NRAs normally have or should have. Examples of static information from NRAs are adding traffic signs to the maps (since NRAs should know where the traffic sings are) and lane-level precision. Examples of dynamic information from NRAs that could improve HD maps are temporary road works and accidents. However, it is crucial to note that since there are many countries with many road authorities in each one with different attitudes towards CAVs, establishing such collaborations at scale seems very challenging at the moment.

4.1.2.3. Infrastructure classification and ODD definition

An interesting and helpful concept that has been considered by many CAD experts and researchers is classification of infrastructure. Infrastructure support levels for automated driving (ISAD) have been proposed before within the INFRAMIX project to classify (digital) infrastructure in terms of its capability to support vehicle automation functions. During our interviews, it was suggested by one of the experts that combining physical quality level with digital support and HD map quality for each specific segment of infrastructure could lead to standard certificates for road segments that could be used to clearly define ODDs for CAVs. This classification could also be used for safety testing and standardisation of ADS capabilities in specific classes of infrastructure.

4.1.2.4. V2X connectivity

Our interviews reveal that OEMs generally believe V2X connectivity could be useful and improve the performance of ADSs. The common belief is that redundancy in information (provided by different sources) means less prediction for ADS and is always useful if available. However, the information provided via V2X connectivity will not always be available and reliable. Therefore, ADSs should not be designed to rely on connectivity information for their core functionalities, at least at this moment. Moreover, liability issues in case of accidents caused by inaccurate information received via V2X connectivity are not resolved at the moment. When decisions of an ADS are made based on the information received from external sources, some form of trust or procedure for verifying the accuracy of the information should be in place. How this should be integrated into the decision-making process, is an open topic for research. Therefore, OEMs at the moment design with the assumption that V2X connectivity will not be available anytime soon.

Data collection and sharing with CAVs

There are various types of data that could be collected with CAVs and shared with other stakeholders for multiple purposes that all eventually contribute to successful deployment of CAD. Here we categorise them into three classes and discuss them separately.

Traffic safety data

CAVs could collect two different types of data that could be used to improve traffic safety. The first one is related to dangerous infrastructure situations, both static (e.g., lack of lane marking in critical places) and dynamic (e.g., slippery road segment). The second type is related to dangerous behaviour situations, such as near misses and state of the driver. Some OEMs, to some extent, collect such data but standardisation, large-scale collection and sharing such data can have significant positive impacts on safety of CAVs by creating new possibilities. If the vehicles collect and store contextual information before and during near misses or accidents, this information could revolutionise safety research and accidentology by enabling new research and design methods that were not possible before. For instance, currently the cycle time for redesigning vehicles to improve safety is 4-7 years because the safety redesign is currently happening based on ex-post analysis of accidents and improving the design in the next generation of vehicles. But traffic safety data collected by CAVs could reduce this cycle time to a few weeks, for two reasons: 1) safety data could become available in much higher quantity and in near-real-time, and 2) safety could be improved through software (which could be updated over the air) rather than hardware redesign (which only affects the next generation of vehicles).

Real-time traffic data

Data collected by CAVs could be used for real-time traffic estimation as well. Although various types of data from different sources is currently being collected for traffic estimation (e.g., mobile phone data, floating car data), CAV data could improve the existing traffic estimation methods.

HD map data

There is a variety of data that could be collected by CAVs and used to improve HD maps. Most of the data types in categories mentioned before could be used to improve the accuracy of HD maps and to enrich their static and dynamic attributes. Apart from the mentioned data, in principle, ADSs could be trained to look for inconsistencies between what they perceive from the environment and what is available in the HD map they are using, which could constantly improve the accuracy and richness of HD maps, particularly if a large number of vehicles do the same and share data with HD map providers.

Currently some HD map data is, at a very basic level of detail, shared between OEMs and the provider of their maps. However, there are many challenges with collecting and sharing all three categories of data mentioned above at a desirable level of detail. These challenges are discussed in section 0.

4.1.3. Effective interactions and collaborations

In this section we describe successful use cases and collaborations related to CAD to provide a glimpse of things that are going well.

4.1.3.1. Successful use cases

From OEMs' perspective, robo-taxis in very limited geographical areas with clear ODDs, industrial uses of automated vehicles in logistics sites (e.g., Amazon warehouses and surroundings as well as port and terminal areas), geographically constraint semi-public places, such as university campuses and airport, and highway autopilot for consumer vehicles in the US are, to this date, successful use cases. The main reasons for success of these use cases are controlled environments and absence of legislative barriers in places where they are deployed.

4.1.3.2. Within-fleet connectivity

Although the existing cases of (within-fleet) connectivity is cellular (not to be confused with V2V connectivity using vehicular ad hoc networks (VANETS)) and not completely real-time, they show glimpses of how V2X connectivity might work and be useful in the future. For instance, (development) Volvo cars equipped with ADS use applications where, for example, when a vehicle breaks down, its hazard lights are automatically activated, and the location of the vehicle will be shared with other Volvo cars equipped with the same system via cellular networks. This happens almost in real-time. Other information relevant for HD maps (e.g., slippery road and road works) are also shared among vehicles by updating the HD map in almost real-time. ADS-equipped vehicles produced by Mercedes also use similar mechanisms for informing other vehicles (within the same fleet) of emergency situations.

4.1.3.3. Map provider and OEM collaborations

The collaboration and data sharing between OEMs and HD map providers appear to go smoothly at the moment. Generally, HD map providers provide maps to OEMs under the condition that certain data collected by the vehicles should be shared with them. There is a clear benefit for OEMs in this transaction since sharing this data will contribute to improving the maps they are using.

When multiple OEMs use maps from the same service provider, naturally all OEMs are benefiting from data provided by other OEMs. And since the number of HD map service providers in the market is very limited, most map providers work with multiple OEMs, which means great potential for sharing data. Another form of collaboration between OEMs is multiple OEMs collectively buying a map provider and naturally, operating and sharing the same mapping services. This gives OEMs even a higher motivation to share data to improve HD maps since they part own the map. Example of such case was in 2016 when BMW, Audi and Mercedes purchased HERE maps provided by Nokia. Finally in cases of companies like Google or General Motors, they develop their own HD maps. Therefore, not only the motivation for sharing map data is strong, the coordination and standardisation of sharing is simple as well.

Apart from the current collaborations mentioned above regarding map data sharing, there is room for other types of sharing as well. For instance, if there is map provider A, the data that it is probing from the fleet (that uses map A) could be relevant for map provider B and vice versa. In that case, there is a possibility for building a business around sharing that data with all map suppliers and thereby all the maps could grow more accurate overtime. However, finding business models beneficial for all is very challenging.

4.1.3.4. Successful countries for OEM and NRA collaborations

Japan and China were recognised by some OEM representatives as examples of countries where OEM and NRA collaborations happen easier. In case of China, the government heavily invests on infrastructure (which could benefit both CAVs and other road users), knowing that the investment from OEMs will follow. This investment aids in successful deployment of CAVs and reassures OEMs that the government supports CAD. In case of Japan, the government has the power and the will to bring OEMs, NRAs and policymakers to the table to interact and collaborate, and OEMs like Nissan and Toyota follow. Moreover, OEMs and their tier 1 suppliers are more closely connected in Japan.

4.1.4. Ineffective interactions

In this section, we describe interactions and collaborations that are required for successful deployment of CAD but are not going well at the moment.

4.1.4.1. Collaborations among map providers and with NRAs

Clearly, different providers of HD maps are in direct market competition with each other. Although competition can sometimes motivate companies to improve their services, in this case collaboration and data sharing among different map providers could have more benefits for all CAD stakeholders by improving the quality of maps that all OEMs use. Currently, there is no regulation to force or encourage data sharing among different map providers as well. Without a clear business interest and in absence of regulations to force this collaboration, data sharing among different map providers is difficult to imagine.

Road authorities have some information that could improve the quality and richness of HD maps as well. Examples of such information is road works, accident locations, temporary road closures, location of traffic sings, speed limits and variable message signs. Although some NRAs are considering developing digital twins of their roads, which could be used to improve the accuracy of HD maps given the collaboration between NRAs and map providers happens, there is no current action regarding large-scale and systematic data sharing between map providers and NRAs.

4.1.4.2. OEMs sharing safety and traffic data

We discussed different types of traffic data that could be collected and shared by OEMs to improve CAD in section 0. However, this data is not shared at the moment due to the following reasons. The main reason often mentioned by OEMs for not sharing this data is protecting data privacy. Also, OEMs know this data is valuable and can give them competitive advantage over other OEMs. Moreover, it might reveal information about the performance of their systems (e.g., revealing false positives in sensors) and provide possibilities for one-to-one comparisons with other OEMs, which are not necessarily desirable for OEMs (although some believe sharing data that could prove safety of ADSs is not only good for the reputation of specific OEMs but also could benefit the general reputation of CAVs). The next reason is cost; training the system to collect new data that is not necessarily required for the main functionalities of ADSs, storing this data and sharing it involves extra costs to OEMs. In addition, clear standardisation of data content and format as well as storage and sharing infrastructure is required to define the exact information to collect and the repository to share the data. Although some general standards for CAV data sharing exists in Europe at the moment, they are not sufficient for large-scale and harmonised sharing of data. Finally, this data might cause liability issues. If (inadvertently) inaccurate information shared by an OEM causes an accident, they might be liable, especially in countries like the US where companies can be sued easily, this might be worrisome for OEMs.

4.1.4.3. Legislation

Perhaps the most important area of CAD where the developments have not been as expected, in Europe in particular, is legislations related to CAD. There are some developments and standardisations related to functional safety and safety of intended functionality (SOTIF), which might concretely define what is expected from OEMs in terms of proof of safety before making their CAVs commercially available. However, the legislation is clearly behind the market. For example, OEMs like Mercedes currently have vehicles with L3 functionalities available at the market (they can be purchased upon request in Germany), but current legislations in Germany only allow L3 functionalities to be used at speeds below 60 km/h, which practically restricts them to traffic jams. Such legislations significantly hinder large-scale adoption of CAVs.

All in all, establishing the full legal basis for public deployment of CAVs seems far from being realised in Europe.

4.2. Challenges within the CAD ecosystem and potential solutions

In this section, we describe the challenges involved with successful deployment of CAD, particularly in terms of collaborations between different stakeholders involved with CAVs. Since at this stage there are many challenges involved with CAVs, we describe the challenges in broad categories and provide some examples for better contextual understanding of practical issues involved.

4.2.1. ADS capabilities and Safety

4.2.1.1. Sensors and perception

ADS capability depends on sensor capability in terms of range, quality and reliability (e.g., false positive rate). Current sensor capabilities are not sufficient for unsupervised automation within an extended ODD. Therefore, one of the first challenges in taking CAVs to the next level is improving sensor capabilities.

AI algorithms used in ADSs for object and event detection and environment perception are rapidly improving; however, they need a major leap in order to make unsupervised automation happen.

But both sensor capabilities and AI algorithm performance are expected to be continuously improved.

4.2.1.2. Proof of safety

One of the unresolved issues regarding the performance of ADSs is certifying AI used in ADSs and unified standardisation of functional safety. Functional safety standard (ISO 26262) and its supplement SOTIF (ISO/PAS 21448:2019) pave the way towards unified standardisation of ADS functionalities in terms of safety but affecting design and ODDs (by definition, SOTIF refers to the absence of unreasonable risk due to hazards resulting from functional insufficiencies of the intended functionality or by reasonably foreseeable misuse by persons). However, this could cause other issues since 1) proving safety of intended functionality on an extended ODD requires a large amount of data (which can only be collected by CAVs using their ADS and recording data), and 2) approving the extension of ODDs will always require ADS performance data for places that are not part of its ODD.

A potential solution for collecting data outside the ODD is using sensors and ADS in shadow mode (active in the background but not engaged with driving) and collecting and analysing performance data to assess the safety of ADS in new ODDs.

4.2.2. Infrastructure

4.2.2.1. Physical infrastructure

List of infrastructure improvements that could improve ADS performance are mentioned in section 4.1.2.1. the main challenges in this area are standardisation and harmonisation of infrastructure elements, and the cost of retrospective adjustment of existing infrastructure. The silver lining is that there is a consensus among OEMs that clear and high-quality physical infrastructure and safe roads for humans are safer for ADSs as well. Therefore, such investments could be seen as no-regret measures since they improve safety for all road users.

4.2.2.2. HD maps

Although HD maps are improving rapidly and there is many good news regarding interactions and collaborations required for further improving their accuracy, their large-scale use in CAVs faces many challenges.

Since HD maps are generally intended be global, their accuracy in all areas and scalability of the detailed information they include is a major challenge. Furthermore, since they include dynamic information that change in time (e.g., temporary road works), they require constant maintenance to keep the dynamic information they contain updated.

Next major challenge regarding HD maps is quality standards. OEMs need to have some assurance that the information provided by maps is accurate and reliable. Quality standards such as Automotive Safety Integrity Level (ASIL) and Advanced Drivers Assistant System Interface Specifications (ADASIS) could be used to assess the quality of HD maps. But current maps do not meet such standards at a level that OEMs consider sufficient. For instance, ASIL includes ASIL A, B, C and D in increasing level of quality; current HD maps do not even meet ASIL B standards. This is because the infrastructure is constantly changing. In order to keep the maps updated with all the dynamic changes in the infrastructure, large fleets of CAVs must be on the roads to collect dynamic infrastructure data. This will remain a challenge as long as high market penetration rates of CAVs are not realised. Further requirements for dynamically updating HD maps using CAVs data are intelligent algorithms to detect changes in the infrastructure, rapid sharing of this information with map providers, and rapid updates of the information.

Barriers in collaborations between HD map providers and road authorities to improve the accuracy of HD maps is another challenge they face. The main challenge in this area is that there are many countries with many road authorities with different attitudes towards CAD. Establishing productive collaborations with all does not seem to be possible without some regulations or incentives.

Lastly, systematic improvements on HD map quality and richness using information collected by CAVs is technically and operationally incredibly challenging. The general steps required to perform this procedure systematically are listed below.

1. All infrastructure elements or dynamic events to be recorded need to be clearly defined in advanced with a high level of accuracy (e.g., slippery road).
2. The ADS needs to be trained/adjusted to actively look for them and recognize them. If there is a databased of items to look for and clear methods for recognising each, this is technically feasible. However, anomaly detection without specific items to recognise (i.e., expecting ADS to recognise any anomaly in the environment) is an open research topic at the moment and not technically feasible.
3. The contextual information and attributes to record when mentioned items are detected should be clearly defined for each situation type.
4. The information needs to be directly communicated to relevant sources or stored and transferred, which requires connectivity, standardisation, and data format clarification, and

in case of storage, storage capacity.

The main technical challenges with such an operation are having a robust perception system including accurate sensors that can recognise the events reliability, and computational power requirements. Storage and/or connectivity infrastructure, standardisation and data format definition, reliability of the information collected by CAVs, and liability for inaccurate information that could cause problems are other challenges involved with this operation.

Given all the challenges mentioned above, most OEMs do not heavily rely on HD maps at the moment. However, it should be noted that, as described in section 0, some level of data sharing between OEMS and map providers is already in place. Moreover, existing HD maps are extremely useful, even in limited ODDs, and are expected to be improved constantly.

A potential solution to overcome some of the mentioned challenges is OEMs controlling HD maps they use by owning the mapping service to have the motivation to share data and to control the entire HD map data life cycle. This will eliminate collaboration and standardisation barriers. If multiple OEMs collectively own one map provider (e.g., the case of BMW, Audi and Mercedes purchasing HERE maps provided by Nokia), data sharing among OEMs is ensured as well, which could further improve the quality of the maps.

4.2.2.3. V2X connectivity

Currently, the main challenge regarding V2X connectivity is its availability. At the moment, there is no V2I infrastructure available, no V2V connectivity possibility among vehicles from different OEMs, and a very limited number of vehicles from same OEMs who can communicate. Even in the future when market penetration rate of CAVs is still low and V2I is either not available yet or only available in very limited geographical places, investments on V2X connectivity and relying on it are not logical choices for OEMs. And if OEMs do not invest on connectivity, road authorities have no incentive to invest on Europe-wide V2I infrastructure and vice versa. No party wants to invest on connectivity until it can be used, and it cannot be used until there is investment. This is a classical chicken and egg problem that seems to be difficult to solve.

Another challenge with connectivity is standardisation of radio access technologies and their quality of service. This requires many committees and intense bureaucracy, about which OEMs seem to be pessimistic at the moment.

The next challenges with connectivity are reliability of the connection in different environment (e.g., in places where there is wave interference from the environment), and reliability of information received from communications to be used for making critical decisions. Also, liability issues in case of inaccurate information received from connectivity are unresolved at the moment.

Finally, ensuring data privacy within connectivity and data exchange procedures is another challenge with connectivity.

4.2.2.4. Clear definitions of ODDs

Clear definitions of ODDs for each ADS functionality are required for guaranteeing the safe operation of ADSs as well as for safety standardisations. However, clearly defining ODDs is still a major challenge, given that many factors affect ODDs and the performance of ADSs in different ODDs.

The main reason is that physical infrastructure is not standardised in Europe. Different countries have different standards for different road types, which makes it hard to define a clear classification for physical infrastructure. The next reason is that there is no functional classification for digital infrastructure and HD maps neither. Another factor that could aid in defining ODDs for each ADS clearly is vehicle probe data and evidence of safety in different segments of infrastructure. Although this data is becoming increasingly available, it is not sufficient yet.

A solution could be introducing regulations that define which functionalities are allowed where or to dedicate specific parts of networks to ADS (in mixed traffic) and starting to invest on infrastructure in those areas, but this needs close collaboration of OEMs and road authorities. These areas could dynamically evolve in time as more data becomes available regarding the performance of ADSs. However, according to some OEM representatives, there should always be room for field learning since there are always previously unseen situations that ADS needs to cope with and without field learning, ADSs cannot develop the ability to deal with unseen situations. For instance, there are new phenomena on roads today (e.g., electric scooters and micro-mobility vehicles) that were not common before. ADSs must learn how to deal with such vehicles by experience.

4.2.3. Data exchange

4.2.3.1. Gathering vehicle probe data

Vehicle probe data is data recorded by CAVs regarding ADS performance. This data could be used for variety of purposes such as training ADS software, proving safety of ADS, and extracting traffic safety, real-time traffic information and HD map data described in section 0.

The main challenge with probing data from CAVs in general is having a large fleet of CAVs on the road to collect sufficient data for different ODDs. For instance, traffic fatality rate in the US for conventional vehicles is 1.11 deaths per 100 million miles travelled. This means the evidence of thousands of miles travelled with CAVs is needed to show they are safer than conventional vehicles. At the moment, only Tesla has a fleet large enough to gather such data. The rest of OEMs who have a relatively small fleet of development vehicles on the road face major challenges in gathering sufficient data. The solution appears to be running ADSs in shadow mode and collecting data even when the ADS is not actively taking over the dynamic driving task. Some OEMs such as Volvo and Mercedes are currently doing this to some extent. However, the clear solution to collecting sufficient vehicle probe data is having a large of CAVs on the roads.

Regarding traffic safety data, real-time traffic data and HD map data described in section 0, the four-step procedure explained in section 4.1.1.3 (defining events, training the software, defining information to be recorded, and transmitting the data) and the challenges regarding robust perception systems, computation power, storage and connectivity infrastructure, standardisation of data, reliability, liability and data privacy apply to all three types of data.

4.2.3.2. OEM data sharing

Currently, OEMs do not share the data mentioned above with other stakeholders, except for the data they share with their HD map provider. Of course, computational, operational and legislation challenges mentioned above are hurdles on the way, but there are other reasons why this sharing is not happening at the moment as well. These reasons are listed below.

- Data privacy protection and legal issues it might cause.
- OEMs know this data is valuable and can give them competitive advantage.
- Revealing competitive secrets and comparison with other OEMs (e.g., sensor or environment perception performance).
- Standardization (i.e., what data to collect and with whom to share)
- Cost of collecting and sharing data.
- Liability issues (e.g., OEMs can get sued easily for many things in the US)
- Risk vs. gain; all in all, the risks seem to outweigh the gains for OEMs at this moment.

On the bright side, a potential motivation for OEMs to share data is the incentive for improving their reputation (and the general trust in CAVs) by showing safety of their CAVs. Some OEMs (like Volvo) want to be in the front of safety. The best way to prove that they are the safest is to make the data publicly available. Then they can truly earn credibility. So, this may be an incentive for some OEMs to share data. They can go beyond showing basic data for branding, but really showing hard facts related to accident risks with CAVs and showing that the risk with these types of vehicles is much lower than other vehicles, or the risk is getting lower and lower over time. This could show that they have introduced a technology that actually makes a difference. In short, it would be very useful if OEMs could continuously publish such safety data for each step and show that the technology is in fact improving continuously.

4.2.3.3. OEM and NRA collaborations

Clearly many CAD issues require collaborations between OEMs and NRAs, but the collaboration does not seem to be effective at the moment. The following were identified by OEM representatives as the main reasons why this collaboration faces challenges.

- Different planning horizons: NRAs have a long planning horizon for their investment decisions (usually 10-20 years) while OEMs usually plan for shorter horizons (up to 5 years). This naturally causes issues for aligning their goals and perspectives. For example, the long planning horizon of NRAs is a problem for some OEMs since for instance, sensors and computation power evolve too fast to plan for 10-20 years ahead.
- There are many different road authorities (national, regional and municipal level road authorities in many countries), and many different attitudes among them. Dealing with all of them is a major challenge for any entity.

- Clash of cultures and goals; apart form long planning horizons, NRAs have long decision-making processes and complicated bureaucracy as well. This does not suite OEMs' ways of operating and decision making. Moreover, NRAs budget comes from public funding, which means their decisions should benefit the whole society, while OEMs are more driven by business interest and are not constrained by such issues.

An effective solution for bringing OEMs and NRAs around the table for collaborations seems to be European working groups and bodies such as ACEA, ERTRAC that have been very useful in the past, at least in initiating the conversation. Yet the issue with such bodies is that usually people who represent OEMs in these groups are relatively detached from their own organisation since OEMs choose people who are familiar with NRAs' culture to interact with them. Also, OEM-NRA collaborations at national level in Europe is scarce at the moment.

4.2.4. Other challenges

4.2.4.1. HMI

The main challenge regarding human-machine interaction (HMI) is dealing with safety, ethical and liability issues of humans monitoring ADS L3. It is becoming more and more clear that this can cause safety hazards and liability issues regarding determining the responsivity in case of late or problematic human takeover are still unresolved. Some even believe such systems are not ethical. The next issue with regards to HMI is accidents caused by other road users not following the rules in situations where human drivers can predict such behaviour and handle the situation but ADSs may not be able to show the common discretion that humans usually do. These are topics that are currently being researched and solutions for these issues are not easy to imagine at the moment.

Another important challenge in this area is HMI interface standardisation. Currently, different OEMs have different HMI interfaces for interacting with ADSs. This means moving from an ADS provided by one OEM to another can cause issues. Ideally, humans should be able to understand the HMI interface intuitively and deal with different HMIs provided by different OEMs without issue. But this needs unified HMI interface standardisation, which is not currently in place. The obvious solution is developing common standards for HMI interfaces, which requires the collaboration of OEMs and standardisation institutions.

4.2.4.2. Legal framework

As described in section 4.1.1.5, CAD legislation in Europe is lagging the technology developments. A comprehensive functioning legal basis for CAVs is not on sight at the moment, which is a major challenge in large-scale success of consumer CAVs.

4.2.4.3. Cost

Cost of the sensors, cameras, research and development for improving ADS software performance as well as the computation power required for ADSs is still an issue for large-scale market introduction of CAVs, particularly given that most OEMs want multiple redundancy in sensors and cameras for safety reasons. However, cost of sensors and computation power is expected to reduce in time. Moreover, techniques such as formal federated learning could allow distributed and edge computing using the computation power of CAVs. This means less computation power requirements in general and eliminating the need for extracting data from CAVs, which could reduce computation and connectivity costs, and resolve data privacy issues.

4.3. Brief summary of key findings

From the perspective of OEMs, the key requirements at this point in time for successful deployment of their CAVs are:

- Sensors and cameras provided by their tier 1 suppliers
- ADS software developed by themselves or companies with whom they have close collaborations
- Legal framework and safety standardisation.

There is no challenge with collaborations required between OEMs and their tier 1 suppliers for sensors and cameras. The only improvement required are improvements in performance of sensors as well as gradual reduction of their prices, which are expected to happen.

Regarding the ADS software, there is no collaboration barrier, but the performance of ADSs should be improved significantly to make the next-level CAD a reality.

With respect to legal framework, CAD legislation in Europe is lagging the technology developments. A comprehensive functioning legal basis for CAVs is not on sight at the moment, which is a major challenge in large-scale success of consumer CAVs.

5. Telecommunication service provider engagements

As part of the stakeholder engagement, a number of organisations provided input on the Telecommunications elements that support the delivery of Connected and Automated Mobility. In order to get a wide market view of the challenges and drivers in this area from market leaders, it was arranged that 4 key bodies provided input to help National Road Authorities understand the market thinking and dynamics in this area. These were:

1. A Global Mobile phone company heavily involved at a European level in the use of mobile connectivity to support the deployment of both CV and AVs.
2. A Global Intelligent Transport and Emerging Mobility provider who provides Road Side Units and deep integration capability at the back end for overall Traffic Management solutions.
3. A Global Traffic Infrastructure provider, focusing on on-street devices and C-ITS
4. A global, cross-industry representative body focusing on Mobile phone utilisation within the CAV ecosystem, bringing the automotive, technology, and telecommunications industries (ICT), working together to develop end-to-end solutions for future mobility and transportation services.

The organisations provided input over a series of online meetings to help provide guidance and input from a CV and AV perspective across key elements including:

- People
- Policy
- Technical
- Management
- Transparency
- Security

To support the meetings, a series of questions were created and shared in order to help direct the conversation but were used primarily as a guide to prompt discussion points.

5.1. Interactions with Mobile Phone Company

5.1.1. Required interactions and collaborations

5.1.1.1. Regulation

At a European level, standardised Regulation for Connected and Automated vehicles (CAV) are not in place. There are technical challenges also, in terms of ‘readiness’ of the road and how their particular deployments will work in scenarios such as ‘mixed traffic’. There is a challenge to integrate current and ‘future’ connected vehicles into the mobility space. CCAM is a partnership environment to support integration across all stakeholders, and INFRAMIX is one project amongst others looking at this. 2023 will release new projects via EU funding. The Mobile Phone company believe that there will be mass deployment of automated vehicles with their 4/5G technology by 2030

5.1.1.2. Policy

Policy is another area that needs to be addressed. From a technology perspective, the EU have left the market to decide if 5G or ITSG5 will be the technology to be used to support CAV. Their view is that for the foreseeable future, due to a number of factors including different auto companies choosing different technologies, both technologies will exist together. Over time, 5G will take over as the technology of choice.

5.1.2. Potentially productive interactions and collaborations

5.1.2.1. Adoption Challenges

Regulation for CAV has seen Germany adopt changes that allows L4 use on public roads and it was suggested that France will follow suit shortly. However, the United Nations Economic Commission for Europe (UNECE) bodies involved in this area are not even started at addressing L4 but are looking at L3 at present.

5.1.3. Effective interactions and collaborations

At a Technical level, the 5G network will support the CAV network, even as penetration levels increase. However, the business model will need to be teased out in terms of owners/payers across the public/private ecosystem. Cyber is already accounted for from the NIS2directive and no further work is required it is believed at this point. The business case for any technology deployment should be underpinned by a Zero Road vision (Zero fatalities) and the Societal drivers which support this. There is a need for OEMs to work together with NRAs and an EU funded mechanism to support this model development and definition.

Standards wise, coming from China where significant work is underway relating to CAV and adoption of vehicles into mainstream utilisation, there is significant work underway looking at the ‘Digital Infrastructure for CAVs’ and is close to final version. CACI China are looking to ensure a global alignment and are meeting with CCAM and other bodies in early May (2022) to discuss this approach.

5.1.4. Ineffective interactions

5.1.4.1. Data Integration

Data sharing will be key, and the National Access Point (NAP) is a key functionality to ensure data transfer in the CAV ecosystem. At an EU level, there is a Mobility Data Space activity underway (https://digital-strategy.ec.europa.eu/en/events/workshop-common-european-mobility-data-space). It is possible that the NAP as it currently stands will be sufficient for static data feeds but for dynamic elements, standards development is needed and integration with OEMs, with the It was suggested that the Car2Car consortium looking to support the integration and collaboration with OEMs.

5.1.5. Challenges in collaborations and interactions

5.1.5.1. EcoSystem

At a V2V level, if OEMs aren't working collaboratively, then how can a whole Zero Road vision be enacted. AT a technical level, the latency needs to be considered from a Vehicle to a back end IT systems back to another Vehicle. It is believed that the latency element and the safety criticality is possible via 5G but work is needed to understand what actual use cases are possible.

5.1.6. Potential solutions to address the challenges

5.1.6.1. Stakeholder Engagement

Key stakeholders must be brought together to help both direct and support the direction of CVs and AVs. It is clear that CV and AVs overlap but should not be treated as one market segment, they are made up of two complementary ones that support improved services for the travelling public. To this extent, it is vital that the services and use cases are identified and supported locally and internationally. There is a need for OEMs to work together with NRAs and Mobile Network Operators (MNOs) and an EU funded mechanism to support this model development and definition is needed.

5.2. Interactions with Global ITS Provider

5.2.1. Required interactions and collaborations

5.2.1.1. Insurance

From an ITS hardware perspective, there is no legal blocker to the deployment of CAVs, however insurance is the issue that needs to be 'sorted' to ensure transfer of risk/liability and access to data is consistent across all the regions and if not, at the very least, that EU wide guidelines exist for manufacturers to create devices to. Allow for agreed interrogation and data audit trail capability.

5.2.2. Potentially productive interactions and collaborations

5.2.2.1. Road Side Units

From an RSU perspective, there is the belief that they would be best suited to collaboration with MNOs rather than competing with them. The RSUs can provide the Micro perspective and the MNOs the Macro one. The RSU provider is typically not just about the hardware but also about the back-end data management and interrogation needed to link to NRA network operation requirements.

5.2.3. Effective interactions and collaborations

A typical road-side unit (RSU) coverage will be somewhere between 800m-2km apart, depending on the layout of the road, the local environment etc. This means that a NRA will have to consider the requirement to place RSUs at intervals every 800m alongside the road way, or where they are best deployed.

5.2.4. Ineffective interactions

5.2.4.1. Pilot to Delivery Provision

To drive user adoption, there needs to be significant migration from Piloting to Delivery wide widespread ecosystem engagement. To this end, there needs to be more wide scale 'Talking-Traffic' type projects that identify the services and use cases best suited to V2X communications. At present, it is felt that NRAs are unsure as to the business case as the services are disjointed and across multiple across stakeholders, such as RUS/MNO/OEMs and the cost breakdown between each is not clear.

5.2.5. Challenges in collaborations and interactions

The Safety case implications for services will be a prime driver in their adoption by NRAs it is felt and in time that this can also improve the clutter on the road through eventual removal of Road Side Units. One example would be Shock wave alert and the ability to manage network disruption in a controlled fashion. However, this is linked to Policy requirements as well as consideration for those non CAVs going forward. A key element will be the need for integration of service delivery between RSU/OEMs/Mapping companies as this provides best overall benefit to the NRA.

RSUs have clear EU and international design standards and are not hindered by lack therein. The challenge is in fact how integration with Variable Message signs, existing on street equipment such as legacy controllers, are managed such that a new V2X capability does not require a complete overhaul of existing road side infrastructure.

From a latency perspective, ITSG5 is expected to be in a position to handle all cases though some edge conditions will need further examination. The Spectrum availability is not an issue at present but is something to consider, as well as safe-guarding parts of the network itself, for ITS deployments going forward.

5.3. Interactions with Global ITS Provider and Network Management Systems

5.3.1. Required interactions and collaborations

The organisation looks to ensure interactions and collaborations at a National and International level to help support the deployment of CAVs. They are a member of Zenzic, the UK organisation tasked with supporting and developing a UK test bed capability.

They are a member of the Transport Technology Forum (TTF) and are involved in a working group called SPATula which addresses specifically connected cars. They are also an executive member of Aesin and lead a working group on Clean and Connected Vehicles which looks to bridge the gap between infrastructure providers and OEMs. At an EU level, they are involved with the European Telecommunications Standards Institute (ETSI) and helped developed some of the communication standards for CAV and are a member of Car2Car as well as C-Roads.

These organisations all play key roles in the CV and AV ecosystem and help shape the future deployment requirements of the physical and digital infrastructure as well as identifying risk and mitigations for investment of public funds.

5.3.2. Potentially productive interactions and collaborations

5.3.2.1. Network Management

There is a growing appreciation that the immediate to medium term focus of Network Management needs to be in the area of 'Connectivity and using supporting features within the ADAS (automated Drive assisted system) ecosystem to move towards elements of automation also. The integration of street furniture, digital mapping, back end analytics and alignment with real time road conditions are a key focus for future deployment opportunities.

5.3.2.2. Data Driven Insight

Accessibility of data by NRAs and other 3rd parties, such as insurers etc, can be an opportunity to utilise the data transmitted/saved as part of the Use Case development to demonstrate the data insight achievable. This will be underpinned by the growing emphasis on Data Analytics and the use of emerging technologies such as A.I. to deliver data driven insight capability into NRAs.

5.3.3. Effective interactions and collaborations

To really drive adoption and appreciation of the emerging digital technologies and the back end data analytics that support improved safety and efficiency of the road network, it is vital that key Use Cases are established, identifying key societal and commercial benefits.

5.3.4. Ineffective interactions

Education

The market for connectivity is more software and digital driven rather than civil engineering focused and as such, there is an education needed for all stakeholders in terms of understanding the digital domain and the data driven insight that can be achieved through the use of connected technology rather than looking at just civil engineering investment.

5.3.5. Challenges in collaborations and interactions

There is a challenge in identifying the areas of investment needed for both the private sector and the NRAs alike as clarity on the Use cases are needed to then support the investment of both parties. Some significant commercial deployments from a RoadSide Unit perspective have taken place to date, such as the Austria deployment as well as pilot testbed in West Midlands UK. However, there are to date limited scale up opportunities.

Another aspect that impacts the deployment and penetration rates of CAVs is the integration timelines with OEMs as the car manufacturers debate the choice of technologies to be utilised and the integration requirements with roadside or public authority deployments.

5.3.6. Potential solutions to address the challenges

Entities such as C-Roads at an EU level at a UK level and TTF/Aesin can be powerful elements in bridging the gaps in understanding and helping to establish the Use cases that drive positive business return for road authorities.

The existing Day 1 services identified must be assessed against the technologies available and the priorities of the NRAs. A strong potential first Use Case to focus on mass deployment relates to removing the capital spend for Variable Message Signs (VMS) and replacing them with digital transmission from the NRA into the vehicle, though consideration of non CAVs will be needed. This will provide savings to the NRA but must be done in a qualitative assessment way, through the comparable assessment of key indicators such as queue length, air quality, journey times etc achieved through VMS and then via Digital in vehicle transmission.

It is important to understand that for vehicles that do not have explicit V2X technology on board, that the proliferation of mobile phones can provide a mechanism to achieve this in vehicle communications but in a safe and managed way. For example, work underway in the market is assessing the ability to integrate Network management information with in-vehicle mapping displays that align with strategic and tactical priorities of the NRAs. This will require an understanding of why users and the NRAs would support the use of 3rd party Apps or in-house App design rather than use of Google maps, for example to drive adoption and integration with the needs of Network Management and the OEM and the vehicle user. The key element here being the importance of alignment of the NRAs requirements for the road usage with the information being shown. This can then be assessed in terms of impacts in Air Quality, Journey time reliability etc as mentioned above. For some communications requirements/messages 5G or ITS5G may not be required as the information is not time critical and could use existing communication methods

5.4. Interactions with Global Mobile Phone Representative Body

5.4.1. Required interactions and collaborations

There is a need to clarify within discussions at both policy and technology level that the Connectivity (C) elements are not necessarily the same as Autonomy (AV). It is the view of 5GAA that the role of Connected/Co-Operative, such as those elements within CCAM are not fully discussed or focused on. This is perhaps due to the overtly technical nature of the discussions needed but also the branding associated with Connectivity may not be as persuasive as Autonomous elements.

The lower levels of AV can be delivered without any implicit dependency on Connectivity, but higher levels of AV, such as partial and full will need Connectivity.

5.4.2. Potentially productive interactions and collaborations

NRAs won't have a huge role in the delivery of 'Service' of automation and that the Vehicle Service

Level Agreement's (SLAs) will be with 3^{rd} parties but not necessarily with the public bodies. For delivery of a seamless service to the travelling public, it is important that a level playing field is established particularly around data provision and information dissemination. The NRA may have a role in the facilitation of the services.

From a Connectivity perspective, there has been a push from a number of cities to request a minimum Quality of Service (QoS). Similarly, at a national level countries such as Germany have looked for a QoS with Connectivity of 100Mb/sec and latency of 10ms.

5.4.3. Effective interactions and collaborations

100% of all new vehicles will have either 4G or 5G available in the next few years. As such, it is important that the services being created are understood by the NRAs and key organisations can support bringing Telcos and OEMs together. Their view is that by 2025 all new vehicles will have 4G and by 2025, 10% of vehicles will have 5G.

The growing digitalisation of the vehicle is creating a software base layer that needs regular updating and as an example, OTA updates allows recalls to be managed in a more effective manner.

5.4.4. Ineffective interactions

For delivery of any level of service, it is more important from an NRA perspective to have the physical infrastructure in place, such as reflectivity of lines is of the desired standard, the road surface is smooth and consistent etc. This is business as usual for a number of NRAs but may need higher priorities as C and AVs become more prevalent in the market. For higher levels of AV, the dependency, or integration with the physical infrastructure becomes more important such as Machine Readable signs, updates of asset elements in a timely fashion when they are linked to the CAV decision chain, and availability of up to date Digital Maps.

5.4.5. Challenges in collaborations and interactions

A potential roadmap for deployment of Telecom based services is to use ITSG5 trials to provide the benefit and then migrate to 5G service deployment. However, a range of services (Day 1 etc) can already be delivered by 4G right now. The primarily use of V2V will be based on complex driving situations and as a mechanism to support safety in travel. For the OEMs, such as VW who use ITSG5, they will need to use 2 radio chips in their vehicles, and this will drive the cost up as radio cost is ~10x for Dedicated Short Range Communications (DSRC) elements. The capacity question associated with Mobile Network Operators (MNOs) can be actually handled by 99% of the cases. The real issue is ensuring that the data is available and understood for the driver.

5.4.6. Potential solutions to address the challenges

The Stakeholder recommend discussion with MNOs to help co develop a roadmap of solutions and services but this has not happened to date. A Forum is needed to engage and collaborate and the NRAs could play a role and key advisors in place to help support these engagements. This has happened already with representatives from Finland/Ger/UK/Belgium (Flanders). It is the 'feeling' that NRAs do not want to engage with in MNOs for delivery of services but the cost and business models of an alternative are prohibitive.

5.5. Summary of key findings

An overall summary of the findings from engaging with the key Stakeholders are:

1. The need for defined Use cases to help drive wider adoption and market investment.
2. Importance of distinguishing between Connected Vehicles and Automated Vehicles as both have different requirements potentially, and both elements are at different stages of evolution. The use of ADAS and other systems to support CVs is not the same as AVs all being CVs and vice-versa.
3. Development of commercially driven pilots that allow for the market to sustain their roadmap development
4. Articulation of the business case needed to support the various Use cases, and an overall engagement and collaboration of key stakeholders linked to the value of ongoing investment in emerging technologies and service delivery
5. Understanding the importance of a digital back bone to support a capital, physical infrastructure investment.
6. Creating a framework and supporting body, linked to those already established, to help bring together the various actors across the CV and AV ecosystem and share knowledge and roadmaps for deployment.
7. Challenges in adoption of different technologies needs to be addressed and NRAs must be empowered to procure the best choices linked to the Use cases required
8. Consolidation of technical choices linked to ITSG5 and 5G and linking Use cases to the technologies best suited to their delivery.

6. Other service provider engagements

6.2. Introduction

In addition to road operators, vehicle manufacturers and telecom operators, successful deployment of connected and automated driving will require contribution from a number of other stakeholders. These include, for example, data aggregators, service providers, Tier1 and Tier2 suppliers of vehicle manufacturers, standardization organisations and software companies. Task T1.4 focused on engagement with stakeholders which are relevant for connected and automated driving but are not covered by tasks T1.1 (Engagement with European NRAs), T1.2 (Engagement with automotive OEMs) and T1.3 (Engagement with service providers (e.g. Telecom providers)). This involved studying stakeholders' interactions related to connected and automated driving and the perceived challenges for deployment of connected and automated driving and supporting technologies. Seven stakeholders were contacted and requested to participate in an expert interview. Of the seven stakeholders, four agreed to participate in the study. In total, there were five interviewees, as one of the four service providers participated in the interview with the national road authority.

6.2. Interactions with other stakeholders

6.2.1. Interaction between the vehicle manufacturer and road operator

When asked about the role of the road operator in supporting connected and automated driving, the interviewees had different opinions. One of the interviewees pointed out that the public sector should produce information base for the purpose of predicting whether the requirements of the operational design domain of an automated vehicle will be met on the route of the vehicle. Another interviewee specifically mentioned that the role of the road operator is unclear. Third interviewee recommended that the road operator should have a strong role, especially in the maintenance of road and street network. According to the fourth interviewee, the road operator has a major role, due to the fact that GPS alone will not be sufficient for driving on public roads, and the vehicle may not be able to follow painted road markings in winter conditions. In this case, the vehicle needs other means for following its route or determining its position. Virtual lane markings or perhaps induction based lane indicators are therefore needed. In the current situation, automated vehicles require very controlled environment, such as a motorway, a closed lane or a pre-configured route.

There were also differences in opinions regarding the question how existing roads and roadside infrastructure should be adapted to allow deployment of highly automated vehicles. One of the interviewees was openly sceptical about whether automated driving would be realistically possible on regular public roads in Finland and commented that separate lanes would be needed on motorways for automated vehicles and slow traffic, and this would be unrealistic due to cost reasons. In urban areas, dedicated lanes could be allocated for automated public transport. Especially in winter conditions and at 80 km/h (speed limit commonly used in Finland on rural and interurban roads), the interviewee considered the vision of mixed traffic of traditional and automated vehicles unrealistic in the near term.

Another interviewee had an opinion that automated vehicles should not cause major investment needs for road operators, and automated vehicles should be capable of functioning on roads with a service level that can be sustained with the resources available for road operation. In summary, there should be no adaptations to existing roads and roadside infrastructure, but the public sector should provide a data ecosystem facilitating navigation and providing predictions of road conditions. The third interviewee remarked that the placement of traffic signs should be harmonized, to make them more easily readable for automated vehicles, and automated vehicles should be informed of exceptions to traffic rules and road signs, such as road works sites. In those areas, the automated vehicle should not assume the infrastructure to be unchanged or attempt to drive automatically.

6.2.2. Interaction between service providers and vehicle OEM

One of the interviewed service providers considered the automotive ecosystem slow and conservative. On the other hand, connected vehicles with in-vehicle equipment and services provided by the vehicle manufacturer were expected to become reality. During this period, it is a relevant question for service providers, to what extent the in-vehicle equipment installed by the OEM is really open, in other words, to what extent independent service providers now using their own telematics units and sensors will be able to utilise sensors and other equipment installed by the vehicle OEM. The interviewee also highlighted the importance of right timing of investments to be made by service providers. In case of telematics services, the product design phase takes about 1–1.5 year, but the demand for services, actual deployment, not pilots, may take several years.

Interviewees also pointed out situations in which a highly automated vehicle may require external data sources or support from a service provider as well as categories of information required. These include e.g. situations in which the speed limit is determined based on traffic rules instead of traffic signs observable by the vehicle or the vehicle misses a traffic sign. Exceptions to the traffic rules and traffic signs should also be communicated to the automated vehicle. In practice, this means e.g. road works sites where the vehicle cannot expect the infrastructure to be unchanged and should not expect to be able to drive there automatically, e.g. the lane markings may be missing. The interviewee probably referred to construction sites where lane markings may be missing or incorrect, drivers may be expected to follow instructions given by traffic control staff (e.g. with hand gestures) instead of traffic signs and temporary traffic arrangements in conflict with common traffic rules or traffic signs may be used (e.g. temporary routing of traffic via lanes to opposite direction).

Map data will be needed for routing unless the route of the vehicle is pre-planned. An automated vehicle may also require information on the operating environment to determine whether the requirements of the operational design domain of the vehicle will be fulfilled at the planned time on the planned route. This prediction may be based on different data types such as information on road condition and short term weather forecast.

Road authorities may also be using external service providers to operate their ICT infrastructure and ITS services such as road and street information systems covered by national legislation and the national access points regulated by the European ITS Directive.

6.2.3. Interaction between service providers and road operator

According to one interviewee, public authorities already collaborate with private companies such as telematics service providers to obtain data from vehicles. For example, floating vehicle data is already collected and used by public authorities. European ITS Directive was also mentioned as an important part of the regulation of ITS services and especially collaboration between road authorities and service providers.

In one of the countries covered by the interviews, public authorities operate a national road and street information system. The system was originally developed to support route planning. However, its information content and processes of updating the data have not been designed to provide support for connected and automated driving. In future, it may be necessary to update the regulation related to the system to take into account the needs of automated vehicles and connected and automated driving as well as to make updates to the processes of updating the data. The data needs of highly automated driving are partly covered by the data already available in the system. These include data needed for navigation and route planning such as the functional class of the road, direction of travel, speed limit, turning restrictions and limitations on weight, height and width. In addition, a highly automated vehicle is likely to also have other data needs. These include e.g. the speed limit which may be determined based on the road traffic law instead of a traffic sign. A digital traffic rule database and service are probably needed to enable automated vehicles to make proper decisions. In addition, the required level of accuracy of the information is expected to increase, but the needed level of accuracy is not known yet. For example, information on traffic rules as well as the data used for navigation and route planning may need to be provided on the level of an individual lane instead of the centre line of the road.

6.2.4. Expectations on deployment of ITS-G5 and C-V2X

Four interviewees were asked whether they expect ITS-G5 and C-V2X to be deployed in their own countries. One of the interviewees commented that the currently offered 5G is closer to 4G, mentioned the lack of visibility to proper 5G, with technology not present in 4G networks. The second interviewee expected that most technical solutions will be implemented in his country (Finland) after a short delay. The third interviewee commented that some vehicle models are already equipped with ITS-G5. For deployment to take place, both vehicles equipped with ITS-G5 and ITS-G5 services perceived by human users as useful, required or interesting and therefore contributing to the vehicle purchase decision will be needed. Public authorities should be able to provide services that provide incentives for adoption, and according to interviewee's opinion, they would be safety-related services. The set of services could be built on weather and safety-related services, and this would require collaboration between stakeholders to create the critical mass required. The fourth interviewee expressed his lack of information on the topic and the lack of close collaboration with the private sector.

The fifth interviewee was asked whether he expects ITS-G5 and C-V2X to be deployed in Europe. The interviewee expected that both technologies will proceed to deployment. The interviewee commented that both ITS-G5 and C-V2X could work but they are not mutually interoperable. The interviewee explained that the bandwidth available on the ITS-G5 frequency band is limited, it will not be sufficient to accommodate all the proposed services, and it will not be reasonably possible to allocate frequencies for all services discussed in standardization groups. According to the interviewee, the automotive industry has invested quite a lot in research and development to provide ITS-G5 as a solution, but some industry stakeholders have started to realise that use of mobile networks could be a good alternative.

The interviewee expected mobile networks to develop also in future, since V2X is only one of the use cases. However, it is not clear how the roll-out of different access technologies will proceed in different European counties and how quickly the features in the core network enabling V2X services will be implemented in 4G and 5G networks. The interviewee also commented the technological maturity of C-V2X such as the need to test the solutions also in roaming situations (the mobile network operator serving the vehicle ITS station is different from the one that provided the SIM card for the ITS station) and operation of the services with different access technologies.

The interviewee expected ITS-G5 to happen due to the fact a lot has been invested in it and concluded it will theoretically provide the specified types of services if there is high enough penetration of interoperable equipment. The interviewee expected the services to be realized only if road authorities decide to follow and deploy the required infrastructure. Without the supporting infrastructure and only few vehicles equipped in the short term in the early adoption phase, it will take 8–10 years to reach a stable situation. The interviewee presented a question, what happens during that phase, and pointed out that this will be the most critical period for ITS-G5.

The interviewee expected 5G to happen independently from the actions of the vehicle industry but was not sure whether the automotive industry will adopt 5G for different kinds of services. For this to happen, the mobile network operators or GSMA should address technical issues related to operation of services in roaming situations and network signalling between operators. For applications for which low latency is not critical, the interviewee concluded that C-V2X would be preferred as it is a standard commercial application and the infrastructure is already available. The only problem seen by the interviewee was the sharing of bandwidth but this could be sorted out by the European Commission. However, using regulation to allocate specific services to a specific frequency band would create additional restriction in terms of availability. In future, both 5G and ITS-G5 will be deployed, and a complex combination of technologies may therefore be realized. For ITS-G5, the deployment may be delayed by lack of roadside infrastructure. In case of mobile networks, the mobile network operators will take care of deployment and there would be no need for involvement of road operators.

After the first question on ITS-G5 and C-V2X, the interviewees were asked how and when they expect ITS-G5 and C-V2X to be deployed. The first interviewee commented that the penetration of ITS-G5 will depend on the decisions of the automotive industry to offer the technology in different vehicle models, price points or vehicle categories, but it will be a problem for the automotive industry if deployment of ITS-G5 will not occur in two years. The interviewee expected local deployments of 5G to appear in one year, but expected 5G to be fragmented in terms of radio access technologies. Slightly more time (1–1.5 years) will be required to reach a more uniform deployment all over Europe.

If vehicle manufacturers decide to adopt cellular communication, differences in radio access technology between countries may cause problems (e.g. frequency bands used), and vehicle manufacturers will expect the same radio technology to work everywhere. If decisions related to technology of 5G networks are made by mobile network operators independently on national level, vehicle manufacturers may have difficulties.

The second interviewee emphasized the need to first have vehicles or terminals carried by drivers

capable of receive the messages. Then, a service provider [or other stakeholder] could conclude that the technology would be the only cost-effective way to provide its services. The interviewee also commented that the level of funding for road operation is low and the road operator is already struggling to cover the expenses of repairing damage on roads with the levels of funding available for road operation. Roadside systems are expensive to build, taking into account the calculated benefits, and they would be built on selected road sections at first. The interviewee expressed readiness to help commercial stakeholders with small investments in collaboration and preferred cutting a large investment into smaller parts in a lean manner. The interviewee also explained that it will be necessary to have a large number of receivers for the messages to be disseminated and that there is a question whether it will be possible for the road operator to provide a service that is available only to group of people with specific equipment.

6.2.5. Expectations on use of positioning technologies

Four of the five interviewees considered themselves competent to answer at least one question regarding the positioning technologies to be used a highly automated vehicle. The respondents had different opinions on the positioning technologies required on the interurban road network. One of the respondents emphasized the use of satellite positioning in combination with the capability of the vehicle to use its sensors to follow a lane and to detect obstacles. Another interviewee considered GNSS sufficient. Two other interviewees expected a solution combining GNSS with other technologies.

The respondents were also asked which positioning technologies will be used by highly automated vehicles in urban environments. One of the respondents expected the main solution to be GNSS but also V2X technology to be used to increase accuracy. If the urban environment is fully equipped, local dynamic maps could be used as support to GNSS. Another respondent emphasized the need for accurate positioning due to limited physical space and commented that there should be road markings or something else (e.g. kerbside) the vehicle is able to follow. In addition, the vehicle also needs more accurate sensor systems and capabilities to react to traffic situations to be able to drive safely among other road users, including vulnerable road users. According to the third interviewee, centimetre or decimetre level accuracy would be needed in urban environments, perhaps also in some other areas, and a novel technical solution will be needed to achieve this. In other words, satellite positioning signals suffer from multipath propagation, and multiple sources of information would therefore be needed to determine the position of the vehicle. The fourth interviewee commented that areas with poor coverage of satellite positioning signal such as tunnels and locations between buildings are places where technologies other than GNSS may be needed.

When asked about positioning technologies to be used by highly automated vehicles in special locations such as tunnels or densely built urban environments, the interviewees anticipated different technological solutions. One of the interviewees referred to the use of 5G network and other mobile networks to provide accurate position. Another interviewee had a vision of LED streetlights becoming multipurpose devices which could also be used to provide positioning services if they are upgraded with new technology. The third interviewee proposed that tunnels and streets with tall buildings should be considered separately, and tailor-made solutions should be developed. In tunnels, the vehicle will be able to follow lane markings. In case of accidents or lane markings being unreadable,

the vehicle should stop and wait for the issue to be solved. The fourth interviewee proposed utilizing the sensor data (e.g. radar or camera) measured by the vehicle, correlating this information with known locations and landmarks and use of artificial GNSS signal in indoor environments.

The final question related to positioning was about the sensitivity of positioning technologies to environmental conditions such as weather and status of road surface and the ways to overcome these limitations. The first interviewee explained that GNSS signal is sensitive to environmental conditions, and there is no easy way to address this, as the only possible solution is to complement GNSS with other technologies. The interviewee expected positioning technologies based on Wifi and Bluetooth, local relative location or distance based mechanisms to be adopted, and expected camera to be the most important data source. Another interviewee summarized the impacts of environmental conditions on different sensor technologies, providing data for positioning. Cameras are affected by darkness and by rainfall and snowfall, depending on their intensity. Lidar has similar characteristics, except its ability to better handle light rain and being not affected by darkness. Radar signals penetrate relatively well, and rain and snowfall only affect radar when they form layers on the sensor. The interviewee did not expect GNSS to be affected by weather. The third and fourth interviewees did not directly comment the characteristics of positioning technologies and their sensitivity. Instead, the third interviewee recommended that the human operator should be ready to take the control of the vehicle when the capabilities of the automation system have been exceeded. The fourth interviewee commented that the vehicle has to be capable of recognizing the situations in which the vehicle is no more able to drive on its own, and the vehicle should also have access to metadata to determine which data the vehicle can rely on. In addition, teleoperation of vehicles may become a reality.

6.2.6. Changes to existing roads and roadside infrastructure to address the needs of highly automated vehicles

The interviewees were asked how existing roads and roadside infrastructure should be adapted to allow the deployment of highly automated vehicles and which elements in the road environment need to be readable with the sensors of a highly automated vehicle. The answers to these questions are summarized in Table 1.

Table 1 Adaptations needed in existing roads and roadside infrastructure and elements in roadside environment which should be readable with the sensors of a highly automated vehicle

Interviewee	Adaptations needed in existing roads and roadside infrastructure	Elements in roadside environment to be readable with the sensors of a highly automated vehicle
1	-	- equipment and signs used for traffic control - roadblocks and other equipment used for road closure
2	- placement of traffic signs should be harmonized - information should be provided to a highly automated vehicle on exceptions to traffic rules and signs, e.g. construction sites (information should be provided to the vehicle before entering such area where the vehicle should not expect infrastructure to be unchanged or where the vehicle should not expect to drive automatically, e.g. due to missing lane markings)	- traffic signs - traffic lights - lane markings
3	- separated lanes, at least rightmost third lane on motorways (reserved for slow traffic and automated vehicles) or narrow dedicated lanes for automated public transport on certain road links in urban areas	- lane markings - traffic signs (incl. variable ones) - traffic lights - traffic information - exchange of information with road weather stations, in future: (1) road weather information, location-specific warnings and information provided by road weather

		stations (2) sensor validation and calibration data provided by road weather station
4	- It should not be adapted at all. The automated vehicle should be able to function with the service level that is realistic to achieve with resources available for road operation - Investments should go to digital infrastructure which would allow sensible routing of a trip and allow the automated vehicle to get a prediction of the road conditions.	- What the OEMs are not able to do? - difficult to evaluate if you do not know what the OEMs have installed in their vehicles and what tools they use to solve problems
5	- There is a need to foresee the presence of gateways or ITS stations and to make them connected. Electric power is required for this.	- I do not know, roadside infrastructure is very custom, as there is no high-level standardization for it, and it depends on the uses of the data

6.3. Challenges in deployment of automated driving and supporting technologies

Interviewees' responses were analysed to identify challenges related to deployment of connected and automated driving and the technologies covered by the interview questions. First, results of the interviews were summarized as text. The summaries of interviews were then read, and challenges identified in respondents' answers to questions were highlighted. The individual challenges found in interview reports were then summarized as text, numbered and divided in two categories: technological challenges (Table 2) and challenges related to business case and collaboration between stakeholders (Table 3).

Table 2 Technological challenges related to deployment of automated driving and supporting technologies, identified and summarized from interviewees' responses.

1	The requirements of connected and automated driving for road infrastructure are unclear.
2	Interaction of automated vehicle with human drivers: Human drivers may follow traffic rules

	or not, while automated vehicle will likely be programmed to behave in safe ways such as give way in conflict situations. Human drivers may take the right of way, overtake and create unsafe situations. The automated vehicle programmed to drive always safely will be taken advantage of.
3	The road transport system involves unpredictable elements: individuals make unpredictable decisions, safety-critical infrastructure (e.g. safety railing) can be out of operation and roads get damaged. The current condition of the road infrastructure is therefore difficult to predict.
4	Fragmented deployment of mobile network technologies available for vehicular communication
5	Multiple different types of roads and service. What vehicles can use and what are the minimum requirements cannot be the same for all. (e.g. due to limited resources available for road operation)
6	Automated vehicle needs information about the road such as speed limit and traffic rules and regulation. However, it is not clear how detailed this information should be and how information can be shared on regulations expressed in different ways (e.g. area based regulations).
7	Digital maps and road databases maintained by the public sector have originally been developed for purposes other than automated driving. The applicable regulation does not necessarily cover service to be provided for automated driving.
8	All ITS and infotainment services cannot be realized with ITS-G5 due to the limited size of the frequency band allocated.
9	In case of cellular communication, interoperability between different mobile network operators and different access technologies is not considered when V2X services are standardized and the services are piloted. This may lead to a situation in which the services work when everything happens inside the network of the same operator, but problems will occur in roaming situations.
10	Challenges in fusion of different data sources when determining the accurate position of the vehicle

Table 3 Challenges related to business case of automated driving and collaboration between stakeholders, identified and summarized from interviewees' responses.

1	Private companies may expect returns for their investments in a short time.

2	The role of the road operator is unclear, as there is no consensus or standards on the service concept to be provided by the road operator for automated driving. For example, how much is the road authority or road operator expected to support automated driving, and how the responsibilities are shared?
3	The automotive ecosystem is perceived as slow and conservative, and deployment for new technologies will therefore take years.
4	At low levels of fleet penetration, V2V data communication will not be sufficient to provide connectivity and functional services. On the other hand, no one will be ready to invest if no supporting infrastructure providing connectivity and services other than V2V is available. Putting the conceptual focus only on the vehicle is a problem.
5	Decisions on the deployment of new mobile access technologies are made by mobile network operators in different countries while the car market is global or regional.
6	Costs of installing roadside infrastructure are likely to be high.
7	High costs of providing electric power for roadside equipment and providing mobile network coverage in certain areas.
8	Roadside infrastructure is highly customized, and there is no high-level standardization for it.
9	The sensor capabilities and software of an automated vehicle are known to the vehicle manufacturer but not to other stakeholders. It is therefore difficult to evaluate what the automated vehicle is not able to do and what elements in the road environment should be readable with the sensors of an automated vehicle.
10	In ITS, it takes a very long time for a solution to move from a presentation in an ITS conference to practice.
11	Lack of close collaboration between road operators (or their service providers responsible for roadside systems) and private sector, and therefore limited communication of future intentions or plans about new technologies.
12	Low level of funding for road management and road maintenance.
13	Public sector produces SRTI (safety related traffic information) and RTTI (real-time traffic information) but does not look at the services from the point of view of a commercial stakeholder.
14	It is not clear whether the public sector can provide a service that can be used only by people who have specific equipment.

6.4. Discussion and conclusions

The interviews provided qualitative results on interactions between stakeholders and challenges for deployment of connected and automated driving and its supporting technologies. The study participants were recruited from the contact network of the author, and participation in the study was voluntary. It is therefore likely that the interviewees had more knowledge on connected and automated driving than other similar service providers in Europe.

The interviewees (four service providers and one road authority) had different opinions on the way the existing roads should be adapted to allow highly automated vehicles to operate (Table 1). Among the interviewed service providers, one expected separate lanes to be needed for automated driving while another had an opinion that existing roads should not be adapted at all, and automated vehicles should be able to operate on service level which can be achieved with existing resources for road operation. These two opinions were almost complete opposites to each other. Therefore, the results of the interviews suggest that there is no consensus among service providers on the support to be provided to highly automated vehicles by the road operator or the service providers working for the road operator.

The interviewed service providers had different expectations on the deployment of ITS-G5. One of the service providers expected that road authorities would start deploying ITS-G5 or other roadside infrastructure and making related investments when they see it as a cost-effective option for delivering services to vehicles. Another service provider considered infrastructure outside the vehicle as a key enabler for V2X and commented that no one will invest in a new feature [in vehicles] if there are no other vehicles or infrastructure to support the feature. In the first case, a sufficient number of equipped vehicles or a clear signal of deployment in large number of vehicles would be required before the road authorities would consider ITS-G5 roadside infrastructure as a cost-effective way to deliver their services. In the second case, either roadside infrastructure supporting ITS-G5 or other technology providing connectivity with V2I services would be needed, before vehicle manufacturers or vehicle users would be ready to invest. While many of the specifications of C-ITS services and related protocol stack have been available for a while, no large-scale deployment of equipment using ITS-G5 access technology and related C-ITS protocol stack has occurred so far in vehicles or on roads in Europe. The situation described by the interviewees has similarities with the Nash Equilibrium described in textbooks of game theory. A Nash Equilibrium occurs when no one of the participants of the game can increase their utility by changing their behaviour (Yildiz 2012).

The interviewees had different opinions on the role of the road operator. One of the interviewees concluded that the role of the road operator should be strong, as GPS alone will not be sufficient for driving on public roads, and the automated vehicle will not be able to follow lane markings in winter conditions. In this case, the vehicle needs other means for following its route or determining its position. Virtual lane markings or perhaps induction based lane indicators are therefore needed. In the current situation, automated vehicles require very controlled environment, such as a motorway, a closed lane or a pre-configured route. Another interviewee was in favor of not making substantial adaptations to existing roads and had an opinion that elements in road environment need to be readable with the sensors of an automated vehicle only when the vehicle manufacturer is not able to implement the required functionality itself.

The summaries of the interviews were analysed to identify challenges related to deployment of connected and automated driving and its supporting technologies. The results of the study include the challenges reported by the stakeholders but no effort was made to compare the obtained challenges to positions expressed by different stakeholders in public documents or challenges described in earlier studies.

Based on the results of the interviews, it was possible to identify several services which can be provided by the road operator or service providers collaborating with the road operator to automated vehicles. These include:

- dedicated lanes for automated vehicles
- digital map for navigation purposes (allowing the automated vehicle to navigate)
- detection of GNSS jamming in roadside environment
- road condition information service (to support calculation of vehicle ODD)
- information on traffic rules and signs
- areas or road sections with exceptions to traffic rules and signs (e.g. road works sites where lane markings may be missing or incorrect, traffic signs and traffic rules may be overridden with instructions by a traffic control officer or temporary traffic arrangements not shown in digital maps)
- vehicle sensor calibration services in roadside environment.

This list is based on the outcomes of the interviews. It describes possibilities to provide support for automated vehicles, but it is not intended to be as exhaustive or as a recommendation for deployment as such.

Appendix A: Stakeholders list

DiREC stakeholders list is a placeholder for all contacts available to all partners who possess relevant knowledge for the DiREC project. The list also includes information about their expertise and status regarding their engagement. To adhere to GDPR, the contact information was not included in the list; instead, a contact holder, who is a DiREC partner was listed for each stakeholder and the process of engagement always started with the contact holder, who is known to the stakeholder. Composing such a list allowed all DiREC partners to use all contacts available to other partners to engage with stakeholders relevant to their tasks. Moreover, the information in the engagement status column facilitated convenient progress monitoring of the stakeholder engagement tasks.

Table 4 shows a snapshot of the stakeholders list filtered for completed interviewed. It should be noted that this is a dynamic artifact and will be maintained and updated throughout the project. Moreover, some details are eliminated to preserve the privacy of the participants who did not wish to be identified.

Table 4 Stakeholders list snapshot

No	Theme	Relevant task	Stakeholder category	Contact status	Type of contact	Subject area	Country	Institution	Position
1	Infrastructure design	2.1	NRA	Interviewed	Technical	Connected and Autonomous Vehicles	United Kingdom	National Highways	Team Leader
2	Infrastructure design	2.1	NRA	Interviewed	Technical	Intelligent Transport Systems Group	United Kingdom	National Highways	Senior Advisor
18	Data exchange	2.3	OEM	Interviewed	Director	Automated driving software	Germany	Algolux	Senior Advisor
19	Data exchange	2.3	OEM	Interviewed	Technical	Automated driving software	USA	Helm ai	Technical expert
22	General	1.2	OEM	Interviewed	Technical	Automated driving general	Belgium	Toyota Motor Europe	Technical director
24	Data exchange	2.3	OEM	Interviewed	Director	Automated driving software	Sweden	Zenuity	Senior Advisor
25	Infrastructure design	2.1	NRA	Interviewed	Technical	Senior Adviser Smart Mobility / AD	Netherlands	RWS	Senior Adviser
26	Emerging technology impacts	2.5	NRA	Interviewed	Director	New technologies	Portugal	National Highways	Director
54	Connectivity	2.2	Standardization	Interviewed	Director	Service provider	Italy	Viasat Group	Chief Business Unit IoT
65	Infrastructure design	2.1	NRA	Interviewed	Technical	Connected and Autonomous Vehicles	Sweden	Trafikverket - Swedish Transport Administration	
77	Data exchange	2.6	Service provider	Interviewed	Technical	National Access Point (NAP)	North Europe	Anonymous traffic service provider	
76	Emerging technology impacts	2.6	Service provider	Interviewed	Technical	Weather information	North Europe	Anonymous Meteorological Institute	Senior Research Scientist, group manager
78	Data exchange	2.4	Service provider	Interviewed	Technical	Operator of the Digiroad database	North Europe	Anonymous road service provider	Project Manager
80	Infrastructure design	2.1	NRA	Interviewed	Technical	Motorway Management	Slovenia	Motorway Management (DARS) Slovenia	Director

Appendix B: Interview questions list

An interview questions list was created within the DiREC project. The main purpose of the questions list is to collect all questions related to all tasks that could not be addressed using the existing literature to have a comprehensive database of questions. These questions were categorised based on relevant themes, tasks and relevant stakeholders. Before interviewing each stakeholder, the partner in charge of the interview could filter the questions list and find all questions from all partners that are relevant to the stakeholder being interviewed. This facilitates developing the interview guide described in

Appendix ***C: Stakeholder interview procedure***. Table 5 shows a snapshot of (a small part of) the interview questions list.

Table 5 Interview questions list snapshot

No	Question	Theme	Relevant task(s)	NRA	OEM	Telecom	Data provider	Service provider	Road user	Standardization	Legal
1	What level of automation do your vehicles, or the vehicles in which your equipment is installed, have in the current roads?	General	1.2		X						
2	What is required for the next level?	General	1.2		X						
3	When do you see the next level happening?	General	1.2		X						
4	What type of collaboaration and data exchnge do you currently have with NRAs?	General	1.2		X						
5	What is the biggest obstacle regarding collaboration and data exchange with NRAs? Why?	General	1.2		X						
6	What part of the collaboration and data exchange with NRAs is going very well? Why?	General	1.2		X						
7	Do you see that there is a country or an implementation that would be the most successful to be replicated in the world?	General	1.2		X						
8	Which elements of the road networks are the most critical for this transition to connected and automated driving?	Infrastructure design	2.1	X	X						
9	What are the most challenging physical aspects that NRAs should be taking care of now to support Automated and Connected mobility?	Infrastructure design	2.1	X	X						
10	Are you planning dedicated lanes or carriageways for autonomous vehicles?	Infrastructure design	2.1	X							
11	What are your views on whether autonomous driving will lead to increase in journeys and traffic, and what will be the implications for your network in terms of physical capacity and digital infrastructure and services?	Infrastructure design	2.1	X							

12	Do you think your agency should prioritize support to CAV, for public transport services?	Infrastructure design	2.1	X							
13	Do you have any budgetary estimates for future support to CAV, for physical and digital infrastructure and services?	Infrastructure design	2.1	X							
14	What kind of pilots do you think your agency will benefit the most? why?	Infrastructure design	2.1	X							
15	Which information should NRAs be providing for leveraging the connectivity between vehicles?	Data exchange	2.3		X						
16	What do you rely upon for driving your vehicle: lane markings? Digital twin? Combination of different sources?	Data exchange	2.3		X						
17	Which data sources are dependent on NRAs and which one is the most critical?	Data exchange	2.3		X						
18	Regarding dynamic mapping and updated mapping what is your opinion regarding who should be responsible for this?	Data exchange	2.3		X						

Appendix C: Stakeholder interview procedure

In this section, the stakeholder interview procedure is described. The procedure includes introduction, interview guide containing the questions and answers, and wrap up.

Introduction

The interviews started with a brief introduction of the interviewer, his/her institution, and the DiREC project. Then the interview procedure was explained to the interviewee. The procedure includes measures to protect interviewee's data privacy (e.g., anonymising names), interviewee's approval of interview content (to be obtained after the interview transcript has been documented) and permission for recording the interview. The recording would start after this point. Finally, the interviewees were asked to introduce themselves, their organisation, and their past and current involvement with CAVs.

Questions and answers (interview guide)

The interview guide, which provides the main directions for questions during the interview, includes the main themes, follow up questions and the information checklist.

Main themes

These are the high level questions to ask the interviewees in very general terms. The first draft was usually obtained from the interview questions list for each stakeholder category (Appendix B). Clearly, the questions would be slightly tailored to each interviewee's background and complemented with follow up questions for detail and clarity. The list of questions to define the main themes were prepared before each interview.

Follow up questions

These are questions that are not predefined and should be determined during the interview based on the answers to get more details and nuances about certain topics and to clarify unclear statements. The follow up questions aid in acquiring more detailed information and allow interviewees to elaborate on certain topics, particularly those within their area of expertise. They are also used to ask interviewees to provide examples for more context when necessary.

Information checklist

After asking all questions listed in main themes, an information check list was used to make sure all planned questions have been asked and sufficient information regarding the main themes is collected from the interviewee before wrapping up the interview. Below is a general example of such an information check list.

General questions (state of the art)

- Required interactions between OEMs and NRAs for successful CAV deployment
  - Necessary
  - Nice to haveWhich ones are going well? With whom? Why?

- Which ones are not going well? With whom? Why?
- Challenges in collaboration
- Possible solutions

Task-related questions (e.g., data exchange)

- Main advantages and applications of data exchange among CAD stakeholders
- Main challenges
- Possible solutions

Wrap up

Before closing the interview, interviewees were thanked for their time and knowledge, and the follow up steps were explained to them. The follow up steps included sending the interview transcript to the interviewee and asking for their approval, sending the interviewees the final stakeholder engagement report, and asking their permission for sending them news and updates related to DiREC project. Finally the interviewees were asked if they are willing to join the DiREC advisory group. In some cases, they were also asked to introduce their colleagues who are knowledgeable about DiREC project topics and are willing to be interviewed.