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STAPLE

Practical learnings from test sites and impact assessments

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Practical learnings from test sites and impact assessments

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Author(s) this deliverable:
Niklas Strand, VTI, Sweden
Ewa Zofka, ERICA, Poland
Wolfgang Ponweiser, AIT, Austria
Martin Lamb, Maple Consulting, UK
Abdelmename Hedhli, IFSTTAR, France
Adewole Adesiyun, FEHRL, Belgium

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Executive summary

The overall aim of STAPLE is to provide a comprehensive review of technological and non-technological aspects of the most relevant connected and automated test sites and test beds across Europe and beyond, in order to understand the impact of these sites on the National Road Authorities (NRA) core business and functions. The project will provide road administrations with the necessary know-how on connected and automated driving test sites, with the aim of supporting their core activities, such as road safety, traffic efficiency, customer service, maintenance and construction. The project builds on previous work by CEDR and other national and European organizations, as well as on the consortium's expertise from several relevant research initiatives.

This deliverable presents the practical learnings, an assessment of impacts as well as a socio-economic assessment derived from the previous work performed in work package 2 and 3 consisting of a test site identification (a group of 72 test sites), several electronic surveys, a stakeholder consultation, interviews and test site visits.

Implications for NRAs have been broken down into specific categories as outlined below, with sub-categories detailing individual findings:

- Testing environment, such as highway, urban, interurban
- Type of facility, such as open and closed tracks, off-road trials, data trials and simulation trials
- Use cases including highway chauffeur, platoons and HD mapping
- NRA priority areas of safety, traffic efficiency, customer services as well as maintenance and construction, and
- Role of NRAs, such as test site shareholder, if they provide the road for trials, have an involvement with the test site or are a customer.

The deliverable provides insights regarding various aspects related to impacts of test sites such as for example regarding connected and automated mobility services, the operation of test sites through selected case studies providing an in-depth account of the selected sites and their activities.

A socio-economic assessment considers potential economic benefits that could be achieved through various connected and automated driving use cases, such as increased productivity through automation or machine assist of various tasks. It also considers potential social benefits, such as using robots to undertake mundane tasks, enabling people to undertake value added activities, potential safety gains / risk reduction from automation, and the potential for automation to replace jobs, and what this might mean for the future workforce.

Work package 5 will report on the findings of the other work packages to date. It will also use learnings form this work package to identify gaps and recommendations for future test sites.

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Abbreviations

ADAS	Advanced Driver Assistance Systems
AI	Artificial Intelligence
AV	Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CAD	Connected and Automated Driving
CAM	Connected and Automated Mobility
CCTV	Closed Circuit TV
CEDR	Conference of European Directors of Roads
CV	Connected Vehicle
FMOT	French Ministry of Transportation
GLOSA	Green Light Optimal Speed Advisory
HD	High Definition
HIL	Hardware In the Loop
I2V	Infrastructure to Vehicle
ICT	Information and Communications Technology
IT	Information Technology
ITS	Intelligent Transportation Systems
MAAS	Mobility As A Service
NRA	National Road Authorities
ODD	Operational Design Domain
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PEB	Programme Executive Board
PVD	Probe Vehicle Data
RWW	Road Works Warning
SAE	Society of Automotive Engineers
SIL	Simulation In the Loop
STAPLE	SiTe Automation Practical Learning
TMC	Traffic Management Centre
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VSOC	Vehicle Security Operations Centres
VRU	Vulnerable Road Users
VTT	VTT Technical Research Centre of Finland

1 Introduction

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

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

The aim of the Site automation practical learnings (STAPLE) project is to provide a comprehensive review of technological and non-technological aspects of the most relevant connected and automated driving test sites across Europe and beyond, in order to understand the impact of these sites on the NRA's core business and functions. This project will provide NRAs with the necessary know-how on connected and automated driving tests sites and test beds, with the aim of supporting their core business activities, such as road safety, traffic efficiency, customer service, maintenance and construction.

The STAPLE project consortium will support the NRAs through the following objectives:

1. Provide an overview of connected and automated test sites/beds in Europe and beyond
2. Provide a catalogue of these sites and detail how they contribute to NRA priorities
3. Undertake a detailed investigation into a selected number of test sites including visiting a selection of sites
4. Assess the implications of the findings of the test sites for future NRA options
5. Analyse and report on the practical learnings from test sites worldwide, including gaps where NRA needs are not addressed
6. Provide a report and recommendations for future research and test sites focus.

Objectives 1, 2, and 3 were covered in work package 2 and 3, and objectives 4 and 5 in work package 4, while objective 6 will be targeted in the upcoming work package 5.

In work package 4 specifically, *Analysis and impact assessment of test sites*, the goal was to provide an analysis of data collected in previous work packages, and thereby provide a summary of the practical learnings and insights gained within the STAPLE project. The work includes a detailed analysis and impact assessment of key performance areas, providing an overview of practical learnings from the test sites. Furthermore, work package 4 deals with assessments of the impacts of different test sites, as well as socio-economic impacts.

The report is structured so that the results of the main research tasks (i.e. T4.2, T4.3, and T4.4) are integrated in the separate chapters, although chapter 3 has a main focus on T4.2, while chapter 4 has a main focus on T4.3 and T4.4. All tasks are introduced together with a common methodology unifying the work and followed by final chapter summarising the key findings and next steps of the project.

2 Methodology

In the description of work, the plan was to disseminate research task 4.2 in one deliverable and research tasks 4.3 and 4.4 in another. Due to insights during the project it was decided to combine this into one unified deliverable as the research tasks are interconnected and best presented together. Regarding research task 4.2, which was the main task disseminated in the first version of this deliverable, the ambition as the work started was to provide an extensive report on practical learnings, however, during the course of the project it was revealed that the collection of data was more difficult than expected. Many test sites were not interested in sharing all data that would have been needed to provide the outlined analysis. There were for instance, fewer test sites than expected answered the online questionnaire in work package 3. From the answers that were obtained, it became apparent that some of the information requested was sensitive, with test sites were reluctant to share it. The methodology and outline of the work had therefore to be adapted according to the available data. Among other things, this change meant that, instead of providing key performance indicators, a pros and cons analysis was performed to bring forward gaps.

The final methodology that was set focused on challenges and enablers as the basis of practical learnings, as these are relevant for how to plan for future test sites, and how to get the most benefit out of existing ones. This work was based on information from work package 2 which provided the motivation, use cases, and benefits of connected and automated vehicles (CAV); but also, on data collected in work package 3 were the relevant test sites were identified. From the practical learnings the impact and socio-economic assessments were derived, and iteratively related back to practical learnings. This provides a foundation for future test sites and business models (upcoming focus in work package 5) related to these. For an overview of the methodology see figure 1.

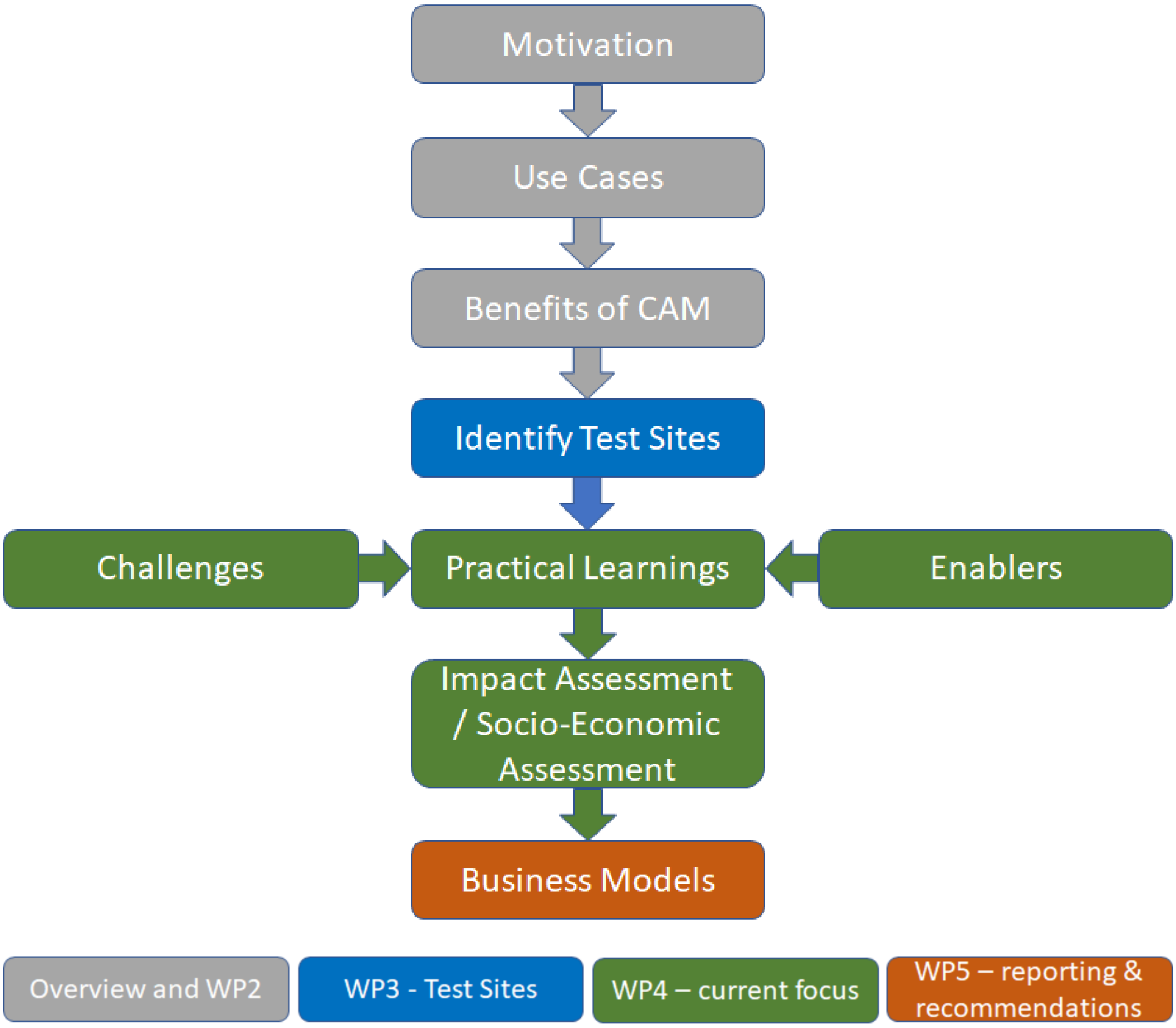

Figure 1. Overview of the STAPLE methodology.

2.1 Levels of automation

Throughout this deliverable reference are made to Society of automotive engineers (SAE) revised recommended practice for taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles and their levels of automation, as described in SAE J3016[1], please note the distinction made between driver support features and automated driving features as the level of automation increases. See figure 2 for an overview of levels of automation.

[1]Recommended Practice J3016_201806, 15.06.2018: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

Figure 2. Levels of automation as described in SAE J3016.

3 Practical learnings from test sites

3.1 Background

In work package 2, over 70 test sites were identified in 20 counties worldwide. A detailed data collection procedure was undertaken for obtaining information on each site, such as location, size, automated use cases tested, type of environment, physical and digital infrastructure support, connectivity employed and other factors. This resulted in a Catalogue of 39 test sites and test beds. A further assessment and pre-selection considered criteria such as location, availability of data, longevity of the site/bed, purpose and confidentiality. This generated a shortlist of 14 sites to be considered during a PEB workshop, (plus 2 additional sites added during the workshop) in Tallinn as part of work-package 3. Finally, 4 test sites / tracks were selected for site visits and more detailed investigation.

The results of the site visits and online questionnaire undertaken during work-package 3 have been further considered and developed into practical learnings in this work-package.

Further, they have been broken down into specific categories as outlined below, with sub-categories detailing individual findings:

- Testing Environment, such as highway, urban, interurban
- Type of facility, such as open and closed tracks, off-road trials, data trials and simulation trials
- Use cases including highway chauffeur, platoons and high definition (HD) mapping
- NRA Priority Areas of safety, traffic efficiency, customer services as well as maintenance and construction, and
- Role of NRAs, such as test site shareholder, if they provide the road for trial, have an involvement with the test site or are a customer.

Each of these categories and their associated sub-categories are considered in turn in the following sections, with a final section giving an overall summary of the findings. The general methodology for practical learnings from the test sites is outlined in Figure 3 below.

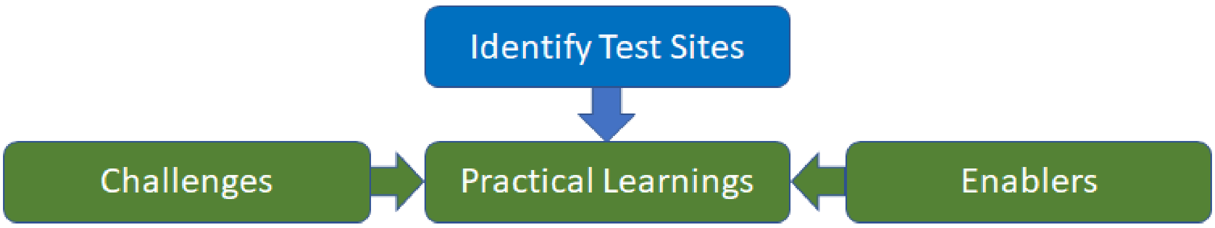

Figure 3. Methodology for practical learnings.

3.2 Environment

The framework condition for automated driving differs a lot depending on the environment (urban, interurban, highway) they cover. A lot of test sites offer several environments within their portfolio (e.g. ALP.Lab, Testbed Lower Saxony), the way they combine the different environments differs from site to site. Some physically connect several road environments to a single route (e.g. TRANSPOLIS), enabling them to also test the interfaces between these environments. Others offer physically separated areas, each of which is dedicated to a certain environment (e.g. Horiba MIRA).

3.2.1 Highway

These test sites are most relevant to NRAs, as they represent the kind of driving conditions typical of motorways and expressways they operate. Where the highway section is a public road, the NRA has at least the role of providing the administration of the according road section. At closed test sites, these sections are usually dedicated to high speed operations to test several domains of technical developments, ranging from vehicle design, safety features up to tests regarding capabilities of communication technologies (e.g. 5G in the TIC-IT project of Horiba-MIRA).

As highways are the most structured road environments (in terms of road design, other road users and roadside technology), automated driving is starting to be implemented there. Advanced driver assistance systems (ADAS) such as adaptive cruise control, collision avoidance, and lane departure warning systems are already commercially available. Advancements in other ADAS areas such as lane keeping assistance, lane change assistance up to a highway chauffeur are close to market and accordingly tested intensively.

Implications for NRAs

This is the most interesting area as NRAs are usually responsible for the highway road sections. Where NRAs are the operator of these roads, they are also involved in the permission of automated driving tests. As the regulative framework of these tests remains at a national level, there are no general rules to derive (e.g. Austria[2]). However, NRAs should have their say in the establishment of these rules to ensure feasible infrastructure requirements.

At several test sites (e.g. Midland Future Mobility) the NRAs also provide access to a comprehensive set of sensor and data infrastructure including radar, laser, closed circuit TV (CCTV), weather stations and roadside units (RSUs). At other sites (e.g. ALP.Lab), the NRAs provide supervision of these tests.

STAPLE was focused on practical learnings from test sites. Furthermore, a view tests are officially reported at open roads, but no detailed information is available to derive deeper learnings from such tests.

The same is true for closed road highway like sections. These are usually ring like high speed test sections. Although there a lot of tests underway, data regarding performance (e.g. safety) is restricted to the original equipment manufacturer (OEM) companies testing at site. To be able to derive lessons learned from such tests it is key that NRAs also get there say at such sites either by becoming a partner or other contractual relationships.

3.2.2 Interurban

Interurban road sections are the most difficult environments for automation.

This results from a risk perspective, as the combination of high speed (compared to urban roads) and an unstructured environment (compared to highways) at interurban road sections. So far, the most prominent accidents of automated vehicles (AV) with fatalities have been at such road sections (Tesla[3], Uber[4]).

About a half of the test sites of the online survey reported that they also include inter-urban road sections. This indicates quite a lot of interest in this area. In the contrary, key roadmaps, like the ERTRAC Connected Automated Driving Roadmap[5] doesn’t even mention interurban

[2] https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20009740
[3] https://www.nytimes.com/2016/07/01/business/self-driving-tesla-fatal-crash-investigation.html
[4] https://www.vice.com/en_us/article/kzxq3y/self-driving-uber-killed-a-pedestrian-as-human-safety-driver-watched
[5] https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf

roads.

Implications for NRAs

Inter-urban roads are likely to play a minor role for (permitted) automated driving in the near future. Potential exceptions are semi-structured roads that provide similar features to highways, such as road equipment and physical separation from the environment. Accordingly, consequences and lessons learned for NRAs will be similar to highways.

An increase in digital infrastructure on these roads, coupled with an increase in vehicle connectivity could lead to short term improvements in areas of traffic efficiency and road safety due to outcomes such as smoother driving and in-vehicle warnings of hazards.

At some stages of the CAV development an infrastructure supporting automation functions will be required. In case such a CAV ready infrastructure is requested by the customers (drivers of the CAVs) not only on highways but also on interurban roads this comes with huge investments. NRAs need to become aware of such a potential situation and prepare and align roadmaps to avoid these investments.

3.2.3 Urban

Urban roads are the most unstructured environments and hence present high technological challenges for automation. So far automation in such areas is focussed on dedicated road sections as well as dedicated use cases characterised by low speed manoeuvres. Two examples of use cases are urban shuttles and valet parking[6] (e.g. Brainport, Horiba MIRA).

At many sites, and especially closed sites, conventional car driving in urban environments is tested. In this case it is quite challenging for the sites to provide all relevant aspects of urban environments. Depending on the functionality to be tested, facilities beyond road design and equipment is required. Examples are buildings, vegetation and off-road space design relevant for localization and communication need to be prepared or at least virtually integrated (e.g. by simulate communications blocking).

Automated vehicles tested at urban open roads are at an early development stage and therefore highly rely on test drivers. It must be ensured that there are clear and strict regulations for such tests to ensure safe testing for all road users.

Tests of urban shuttles are the most prominent ones. Several EU projects[7][8] as well as a lot of national activities already established a lot of experience in how to establish such vehicles on dedicated routes. At least if such tests are performed on open roads drivers/operators are still on board. Important aspects analysed beyond the pure driving task are the interaction of the vehicles with users (e.g. AV Living Lab) as well as the integration of services, enabled by such automated shuttles in the entire mobility system.

Implications for NRAs

Automated valet parking is for dedicated parking facilities and hence of minor relevance for NRAs. Tests of urban shuttles are relevant for NRAs as soon as their interaction with the entire mobility system comes into play. The wide range of services that can potentially enabled by these vehicles have the potential for disruptive changes and as such, it is important that NRAs are aware of these developments, even if they are not directly involved.

Cities tend to have high levels of digital infrastructure such as MIDAS loops, CCTV and APRN cameras, so are well placed to benefit from vehicle-infrastructure interactions for use cases such as GLOSA (green light optimisation).

[6] https://www.bosch-mobility-solutions.com/en/highlights/automated-mobility/automated-valet-parking/
[7] http://www.citymobil-project.eu/
[8] https://cordis.europa.eu/project/id/314190/reporting

The highest relevance for NRAs is conventional car automation, although these developments are in the early stages. Fully automated vehicles on urban roads are to be expected beyond 2030 (ERTRAC Connected Automated Driving Roadmap). The contrary is the case for connectivity, where solutions become more and more available (like the above mentioned GLOSA)

3.3 Type of testing facility

The development of automated driving functions involves a large variety of domains. Accordingly, there exists a chain of tests for each of these domains. Usually this starts with simulation and tests on closed roads and later open road tests for higher TRL levels are performed. On the other hand, novel artificial intelligence (AI) techniques like deep learning require huge amount of training data from the real world. Hence there is a continuous loop of test and development cycle at all these types of test facilities. There are also special use cases that are related to road automation like off road applications and test that are more related to data collection and communication.

Most test sites deliver at least open and/or closed road-testing facilities and potentially in combination with data related use cases facilities. Many test sites are highly adaptable towards the needs of test site users (OEMs etc.). Specific technology or equipment that was mentioned included e.g. localization units, movable targets (dummies), telecom networks et cetera. It was also emphasized that customers bring their own equipment to the sites. However, some sites do specialize and target specific types of tests or use case, e.g. simulation trials only at Midlands Future Mobility.

3.3.1 **Closed road trials**

This is the most traditional type of vehicle testing. Typically, such test fields are made artificially or by re-designating large concrete areas (e.g. airfields out of service). Most of them have a high-speed circuits and further dedicated testing areas like urban layout, Belgian paviour and rough concrete testing, low friction surfacing, off-road driving and others (e.g. Horiba MIRA or ZalaZone).

Other test sites, mainly in the urban context consist of dedicated road sections that are detached from open traffic like campus areas or at least at traffic-calmed road sections (e.g. Test Site Stockholm).

The main advantage of closed road trials is their controlled environment, as this greatly simplifies the preparation and approval procedures. It is possible to repeat tests at constant conditions (traffic, road), so is used for testing of specific functions and use cases like high speed, safety, connectivity, wheel/road interaction, ... The disadvantage of closed sites is the limited transferability of results to real open roads as not all conditions and context constellations can be replicated in an ‘artificial’ environment.

Implications for NRAs

Closed road trials are highly relevant as they provide the base analyses of novel automation functionalities. Especially tests related to the interaction with the infrastructure at all levels from wheel/road interaction up to communication and cooperative intelligent transport systems (C-ITS) will be tested at such closed facilities. Accordingly, it is key for NRAs to have access to such sites to perform their own tests and analyses as well as to learn from related tests performed by others.

3.3.2 Public road trials

To perform tests on public roads is essential for the development of automated driving functions, for real-time data collection, training and learning applications and long-time reliability and behaviour evaluation.

The test sites providing such testing facilities (e.g. ALP.Lab, Testbed Lower Saxony) must provide testing procedures that are aligned with the relevant national legislation. Current initiatives, like the H2020 call DT-ART-06-2020: "Large-scale, cross-border demonstration of connected and highly automated driving functions for passenger cars" is tackling the issue on the harmonization of legislation regarding testing and driving automated vehicles between member states.

Implications for NRAs

Public road trials provide the highest learning effect for NRAs. Especially systemic effects can be evaluated like the role of the physical and digital infrastructure to ensure safe driving or behavioural effects impacting traffic efficiency. Both effects 'road safety' as well as 'traffic efficiency' are key priority areas of NRAs.

All this comes with the cost of the most difficult environment in terms of other road users. To ensure no harm of other road users one must guarantee maturity and reliability of the automated vehicle as well as a test approval procedure that covers all safety relevant aspects. For NRAs it is key that they are involved in these processes and have the final say to release tests on their road.

3.3.3 Off road trials

Typical off-road tests are for utility vehicles driving on unprepared terrain like meadow, field path or even desert or ice. These testing facilities are also used for other domains like military, farming and surveillance applications.

Another off-road application is valet parking valet parking[9] (e.g. Brainport, Horiba MIRA). This is to drop-off and pick-up the vehicle at a dedicated lot and the vehicle (+ the supporting system) is driving automatically to the final parking position.

Implications for NRAs

Such trials are relevant regarding NRAs priority area of maintenance and construction. It is valuable for NRAs looking to investigate construction vehicle capability, such as the recent trial of construction equipment on the A14 (Horiba MIRA), or soft-estate management, such as strimming and grass cutting.

On-road construction and maintenance, such as cone-laying, white lining or applications such as the Colas autonomous impact protection vehicle, could be trialled on other track areas. This is an area that could offer significant benefits to NRAs primarily in safety by removing workers from hazardous environments and in cost, from a reduction in labour and increase in productivity, i.e. as machines can theoretically work 24 hours a day with no breaks.

3.3.4 Data trials

Nearly all tests sites under investigation of STAPLE deal with data collection, data exchange and connectivity, e.g. ConVEX (UK) is a test site that is dedicated solely to data exchange. To support these tests, most sites provide connectivity equipment ranging from ITS-G5 to first 5G trials.

[9] https://www.bosch-mobility-solutions.com/en/highlights/automated-mobility/automated-valet-parking/

Data collection is an essential part for the development of automated driving due to the need of huge amount of data for all the learning techniques used in automation. The key is to provide the most realistic as well as relevant data.

Another topic is the generation and exchange of HD maps of roads. They are required for the automated vehicle localization as well as lane and route decisions. If these maps are enriched with dynamic features, they can also be used for communicating construction site (layout) or even weather and special road surface cases (e.g. ice).

For further information on the exchange of data see section 3.5.5 on cooperation services.

Implications for NRAs

Such tests are key to ensure that data can and will be exchanged and how this data exchange can be performed technically. NRAs should become aware of the data related infrastructure requirements for automated driving. This is for the data exchange (road site units, mobile communication, fibre optic networks) as well data storage and high-performance computing facilities.

Furthermore, it is also important to ensure data availability for the evaluation of other automated driving tests.

3.3.5 **Simulation trials**

Simulation is an essential part of the modern development circle – also for automated vehicles. Simulations can be standalone applications that are feed by available data. But there are also concepts to put simulation and even hardware in a complete real-time loop called SIL: Simulation in the loop and HIL: Hardware in the loop (e.g. ALP.Lab). Other approaches are to provide digital twins of the vehicles tested (e.g. Transpolis) or to perform complete tests virtually.

Simulation areas cover a huge field of applications starting from sensor physics, sensor systems, data fusion, simulation of control and powertrain strategies, fail safe behaviour, cybersecurity attacks, the interaction of the vehicle and the static environment, interaction with other road users, weather conditions, traffic scenarios, power consumption up to socio-economic impacts.

Accordingly, the test sites investigated in STAPLE differ a lot. Most of them provide at least some simulation support or dedicated simulation packages (e.g. Horiba MIRA) and test sites dedicated to simulation (e.g. Midlands Future Mobility/UK).

Implications for NRAs

Simulation trials are essential for the ability of NRAs to upscale local effects of automated driving to their entire network. This is key to enable estimations on the network and system wide effects of CAV as well as the required measures to steer this development such as legal regulations, infrastructure requirements and adaptations and development incentives.

NRAs should have a continuous look on simulations as they provide the earliest insights into upcoming developments as well as their potential impacts. In the same way NRAs should look on the transferability of simulation results and hence validity in real world. Depending on the simplifications and assumptions of simulations their result must be interpreted.

Obviously, simulation trials are of high advantage for NRAs as they highly reduce the necessity for road tests that can disturb NRAs road network. As simulation trials are much easier to repeat and are usually much faster than real world tests, they increase development speed and reduce development costs dramatically. Accordingly, NRAs should also use these tools as much as possible for their developments related to CAVs.

3.4 Use cases

In deliverable 3.1 of the STAPLE project, an overview of use cases from different test sites were provided. In this section a more detailed description of selected use cases and their relation to NRAs responsibilities are provided.

3.4.1 Highway Chauffeur (autonomous level 3 - 5)

Highway chauffeur technology relieves the driver from the driving task as it lessens the need to monitor the driving and driving environment. The use case could be described as autonomous driving on highways and was tested at several of the surveyed sites. Currently the highway chauffeurs on lower levels of automation (SAE L3) are tested and these are viewed as an important step towards full automation. Current systems are handling the both the longitudinal and the lateral control of the car, but connectivity is also considered important for this technology, and this use case to be successful.

Implications for NRAs

Since highway chauffeur technology, as represented by SAE L3-5, is likely to have an impact on traffic efficiency and safety, it is highly relevant for NRAs responsibilities. It will likely affect road infrastructure from several perspectives. For instance, the infrastructure will be used more efficiently due to potentially smaller following gaps and connected features that smooths traffic flow and in terms of safety. At the same time, there could be new responsibilities for NRAs as there could be a need for certified roads to allow for highway chauffeurs, and once it is certified there is also a responsibility issue arising.

3.4.2 Driving robot (Sensing for asset management)

Self-driving robots or drones can be used by the infrastructure operators to conduct infrastructure diagnostics and inspections. Robotics has been used extensively in many fields because it enhances workers' safety, increases production efficiency, and improves the quality of products. It is important to introduce and to encourage use of this technology in highway operations. As an ultimate goal, robotics can be used in all phases of highway transportation: production of highway material, construction of highways (including quality control), highway maintenance and operations (including inspection and monitoring), and performance in hazardous and difficult-to-access environments. The use of drones for bridge inspection are investigated by the EU project AEROBI.

The project INTELO[10], from the French *Inspection télévisuelle d'ouvrages* (Teleoperated Bridge Inspection) has developed a prototype semi self-driving robot for inspection. In the prototype, inspections are teleoperated from the robot cabin (the inspector sits there). In the future version the operator will be sitting in the safe spot outside of the maintenance/inspection area or in the TMC.

Implications for NRAs.

The use of self-driving robots for sensing and inspection of the road infrastructure elements could become a near future reality for the NRAs. The technology is already in place as drones have been in use for over a decade now. Self-driving inspection robots needs to be tested under real traffic conditions to ensure safe operations. Also a cost-benefit analysis needs to be performed as most likely initial cost of purchasing the inspection equipment can be high, however in the long term it may be beneficial to protect workers and increase inspection safety

[10]Sutter, B., Lelevé, A., Pham, M. T., Gouin, O., Jupille, N. et al. (2018). A semiautonomous mobile robot for bridge inspection. Automation in Construction, Elsevier, 91, pp.111-119.DOI: https://doi.org/10.1016/j.autcon.2018.02.013

especially in the areas with hard access such as bridge columns, or piers, etc.

Automated sensing of vehicles used as probes in the C-ITS environment can also bring some significant benefits to NRAs. When vehicles will be connected and equipped with infrastructure scanning sensors such as LIDARs, 3D scanners or cameras they can detect problems with infrastructure while driving and sending this information back to the infrastructure. Then the TMC gets easy and fast information about roadway assets condition. A classic example can be detecting potholes or broken signs, pavement cracks and failures of other infrastructure furniture.

3.4.3 Freight vehicles platooning

The use case of freight vehicles platooning was addressed at several test sites, indicating the importance and potential of technology to enable this technology. The use case is important for sustainable freight transports as is a cooperative technology allowing freight vehicles to drive with shorter time gaps between them (which will reduce air resistance and lead to reduced fuel consumptions); it also allows drivers in the platoon to rest, while the lead vehicle drives. This will affect working conditions for drivers and for logistics businesses to be carried out more efficiently due to factors such as the organisation of the workforce and environmental gains.

Implications for NRAs

Research and trials on freight vehicles platooning have been ongoing for many years and the technology might be positive for efficient use of road traffic infrastructure but might also pose some challenges for connected features in the interaction with road users outside of the platoon. It could be for example the need of communication from the infrastructure so that on ramp viewing can be conducted safely and efficiently. Another aspect of freight vehicle platooning is that they might pose a higher degree of loading on roads and bridges which NRAs must consider before allowing platoons on certain roads, and also when planning new infrastructure so it is prepared for this technology. Another aspect that might be taken into consideration is the design of rest areas in connection with roads. With fewer drivers driving at the same time, the need for rest space decreases as drivers can rest within the vehicle. However, when there is a need to stop the space needed might be larger as a whole platoon needs to fit in at the same time.

3.4.4 Driverless maintenance and road works vehicles

Since automated driving technology will be much more sensitive to deviations in road standards et cetera the importance of road maintenance will be increased. The use case is also supported by HD map technology which may provide information on where there is a need for maintenance making the work more efficient.

Implications for NRAs

With driverless maintenance and road work vehicles the budget for such services could be cut, and as costs goes down road maintenance in areas with less priority could receive a higher standard. This would affect the accessibility of the road network positively and thereby potentially allow a greater proportion of roads to be accessible for CAVs. There could be significant cost savings for NRAs from reducing the need to have a driver in the vehicle, and since vehicles can theoretically operate 24 hours a day, although some external supervision role may be required. Highways England have undertaken trials of automated, or partly automated maintenance equipment and have had a demonstration trial of an autonomous dumper truck on the new section of the A14 constructed near Cambridge. They also procured research on the impacts of connected and autonomous plant more generally.

For road maintenance, the biggest benefit will be safety, from removing the requirement to have drivers or operators on live carriageways. Traditional maintenance in the work zones requires a physical driver to drive the attenuator truck which according to the UK safety statistics 12 road workers lost their lives in the past 10 years and in 2017 there were 150 incidents per month of vehicles encroaching into work zones illegally[11].Thus, implementing automated attenuator trucks in the work zones which will be setting up cones and picking them up (controlled from outside of the work zone remotely) provides great benefits in terms of safety of workers and also cost savings as explained above. First vehicles of this type are manufactured by *Royal truck and equipment* in collaboration with *Kratos* and are used in Colorado, US (line painting truck) and in the UK where contractor Colas is using them in its work operations for Highways England.

3.4.5 Provision of HD maps for automated mobility

Some of the test sites addressed the use case of HD maps which improves the precision of traditional maps. With self-driving technology on our road the room for errors in the map information received is smaller as there are no drivers there to compensate. HD maps can be viewed as an enabler of automated driving as it provides input for the decision making of the car. The use case is realised with a combination of HD maps derived from sensors within the cars but could also be fused with infrastructure mounted sensors that provide information to the autonomous vehicle through connected technology.

Implications for NRAs

The provision of HD maps is important for the next generation of transport and mobility as realised by automated driving features. With HD maps including e.g. more detail on aspects outside the scope of traditional maps, such as analytics on traffic density, vulnerable road users and so forth will have a great impact on transport. It may for example affect traffic efficiency and use of road infrastructure, but it could also serve as input for planning of new road infrastructure.

3.4.6 Human factors

The human factors use case was also addressed by several of the test sites. The human factors are a main concern on intermediate steps towards full automation where drivers are interacting with the automated driving features to a higher extent. The human factors use case includes for instance take- and hand over scenarios, but also evaluation of systems with the driver able to be in the loop. This could be for example drivers trying to counter steer a steering intervention intuitively and so forth. For the automated driving systems to be safe they must be tested together with a human driver, as they are expected to be used once they are on the market and hence public roads.

Implications for NRAs

People in general are the main beneficiaries of transport and mobility, therefore the human factors aspect is important for NRAs as they are customers of the services provided by NRAs. When technology and the built environment are in affinity with the human user of the system, they will be more accepting towards changes in the transport system. For NRAs this means easier anchoring processes when new infrastructure projects are carried out and less resistance in the general population. Also, less data will be collected by humans as NRAs are interested in collecting traffic volumes and infrastructure performance data to be able to provide safe and reliable services to motorists. With automation most of this data will be collected by CAVs and via C-ITS systems send to Traffic Management Centers (TMCs). Thus, there will be a need for organisational changes within NRAs to enhance competences on

[11]Traffic Technology International, March 2019.

intelligent data mining and operating roads in the new cyber reality. Fewer workers will be required to undertake physical maintenance and data collection on the live carriageway, as they will be replaced by robots and CAVs. Provisions for new jobs will be needed in the TMCs with competences towards IT and information and communications technology (ICT), cybersecurity, and advanced traffic management, etc.

3.4.7 Automated parking

The Horiba-MIRA test site amongst others will be undertaking trials on automated parking, including valet parking and parking in multi-storey car park, which will be constructed on the site.

Implications for NRAs

Automated parking is likely to be reliant on an infrastructure for connected technology, for instance to locate a free parking spot without unnecessary detours while "looking" for a spot. This would be positive for traffic efficiency and throughput of traffic, and hence more efficient use of road infrastructure. This would also have an positive impact on air quality, due to fewer vehicles driving round looking for parking spaces – a study[12] commissioned by IBM estimated that 30% of traffic in cities is caused by drivers searching for a parking spot. An infrastructure for connected technology could potentially be part of future NRA work. Furthermore, the planning of parking is likely to be affected by such technology. When the driver does not need to follow the car to the actual parking spot these can be smaller in size as there is no need to open doors, and thus contribute to more efficient space use.

Whilst many NRAs do not have the responsibility for highways in urban areas, should traffic flow be improved through automated parking, there may be knock-on benefits of improved efficiency on entry and exit ramps of highways near urban centres.

3.5 Priority areas

The core activities for the NRAs operations and focus are identified in this project as road safety, traffic efficiency, customer service, maintenance and construction. Practical learnings from the test site visits and the stakeholders' survey for each of these priority areas are summarised below.

3.5.1 Road safety

Most of the surveyed test sites were dealing with different aspects of the prioritized road safety area in relation to automated driving systems. Many test sites cover all SAE levels or have the potential to host testing activities on automated driving systems on the higher levels of automation. The variety of tests offered at the test sites covered almost all possible traffic situations and could be highly adaptable towards the needs of test site users (OEMs, NRAs etc.). Testing activities stretch from more research-based testing, through technical validation and performance testing, towards standardization tests (e.g. EuroNCAP testing). When asked about human-in-the-loop testing, i.e. drivers or vulnerable road users (VRU) used for evaluation of human behaviour in the interaction with automated driving technology most sites reported that they do this or can do this depending on the customer.

Implications for NRAs

One of the most important issues brought up by the test site operators was the need for risk assessment to carry out automated vehicles testing. Some sites have the capability to

[12] https://www.parking-net.com/parking-industry-blog/get-my-parking/how-smart-parking-reduces-traffic

incorporate virtual modelling to improve the need for risk assessment to carry out these tests.

Another issue that may be of interest for the NRAs is the harmonisation of the regulatory procedures needed to perform testing. There does not seem to be a unified procedure to document test work that harmonizes the work between sites, although in some countries there are specific reports that needs to be produced when tests are carried out on public roads.

Some sites also require a contract with the customers that documents safety and cybersecurity issues. There are also site-specific internal protocols and documentation needs that sites use to assure the quality of their testing. Since testing usually is very connected to customers and their needs the creativity among them is driving road safety testing forward.

3.5.2 Traffic efficiency

Broadly speaking, nearly all interviewed sites considered several digital road infrastructure types (sensing, communication) as well as driving functions. The Midlands Future Mobility site in UK reported to perform only simulations, where the others perform the whole chain from simulation over virtual testing up to real world tests. Most sites cover such conditions as: moving traffic, congested traffic and traffic incidents.

The CAV test site in Helmond/NL offers tests for vehicle platooning, priority request and mixed traffic scenarios. The AV Living Lab/SI provides scenarios in the urban environment. Trikala CityMobil2 ARTS/GR offers calculations on energy consumed during tests on specific and overall routes. And Transpolis/FR offers trip optimization for a shuttle based on the real time demand, impacts of different penetration rates, automated vehicle platoons, fuel saving and effects in mixed traffic situation. Other (indirect) impacts of connected and automated driving on traffic efficiency / network management addressed are reported by Midlands Future Mobility/UK on capacity, at Transpolis/FR on increasing penetration rate / upscaling the geographic scope as well as evaluations on HOV and dynamic marking systems.

Implications for NRAs

Testing scenarios that may be of interest for the NRAs in terms of impact of automated driving on traffic efficiency include: digital road infrastructure testing (instrumented highway and communication), simulations in virtual lab, vehicle platooning, trip optimisation: including fuel savings, energy consumption in mixed traffic conditions, and lastly dynamic marking systems.

3.5.3 Customer service

Customer service was a feature in several test sites with trials around new mobility concepts that would extend mobility solutions. These were focussed on first/last mile transport, mobility as a service (MaaS) and automated bus routes. Other use cases included delivery drones, cargo delivery and an urban logistics hub.

Customer perception of CAVs is likely to be a key factor in their adoption, yet only three of the sites are either working to understand perception or to ensure that VRUs are involved.

Two sites are considering social inclusion, with one trialling facial recognition as a payment model and one analysing data to better understand how social inclusion is covered. Notwithstanding issues around privacy and data protection, the use of facial recognition is an interesting concept in terms of social inclusion as presumably there would need to be some sort of smart payment device; there is an inherent risk in excluding a proportion of society who either do not own or are not technologically proficient in using smart devices such as smart phones or tablets.

Implications for NRAs

CAVs have the potential to radically alter traditional business cases of, for example, private vehicle ownership or pubic transport based on fixed routes and timetables, and so this should be an area of focus. Two sites have the opinion that new business models will develop, with one site (AV Living Lab) offering business development and hackathons to actively encourage this, however none of the sites described any new business models that were being considered. One potential new business model will be around insurance, potentially moving away from privately held vehicle insurance, to corporately held insurance for fleet CAVs for example. Two sites (AV Living Lab and CityMobil2) reported that they are insured in a conventional manner. ConVEx, which is a site that provides data to physical trials say that insurance details are shared across their platform, whilst Transpolis has an insurance company as a shareholder in the site and is developing the capacity to conduct tests around this.

3.5.4 Maintenance and construction

In the priority area of Construction and Maintenance, a topic of roadworks warnings was investigated and questions whether any type of advanced roadwork warnings are tested at the test site. Responders replied that they actively test and use all sorts of passive, active and interactive and connected roadworks warnings.

Implications for NRAs

Two test sites replied positively that they do test and evaluate impact on infrastructure furniture with regards of construction and maintenance with potentials to remove obstacles in infrastructure furniture elements causing hazards for automated driving.

Real time data collection by maintenance vehicles was reported by two test sites, where the first and last cone were connected to depot on an iPad to know live roadwork time and as information communicated to vehicles. Winter maintenance was also mentioned and needed; however, no testing has been done so far but can potentially be included in the future.

An autonomous vehicle trial is underway on the construction of a new section of the A14 expressway in Cambridgeshire, UK. The advantages are theoretical 24-hour operation and consistent performance. When the results are available the A14 testing could be of great interest for the NRAs in terms of automated maintenance and roadwork zone safety.

3.5.5 Cooperation services / C-ITS

The deployment of Vehicle-to-Infrastructure (V2I/I2V) and Vehicle-to-Vehicle (V2V) communication, also known as cooperative intelligent transport systems (C-ITS) has the potential to bring many opportunities for the NRA in general and more specifically the road operators. Some of the major opportunities identified are related to road safety, traffic management and traffic information.

Indeed, by deploying C-ITS solutions, the road operator can get improvements in traffic monitoring, event management, traffic management and Road Network Operations in general (increase/optimization of capacity). Road operators can also get the possibility to improve the way they manage traffic information related to road works, road conditions, weather conditions, and diversions to mention a few examples.

In terms of policy and social issues, Safety is one of the most important focus areas where C-ITS is expected to bring improvements, especially in the following safety areas: collision Reduction, Protection for Vulnerable Users, Traffic Condition Warning, Safety of Road Workers in the Field. C-ITS systems can analyse the data collected through V2I/V2V and warn the driver if potential dangers, for instance end of queue warning, work zone ahead or if a car in front suddenly brakes hardly.

Deployment of C-ITS has the potential to reduce the environmental impacts of vehicles through reduced congestion thanks to I2V communication. Some examples of use cases that can help reduce the environmental impact of vehicles are: Green Light Optimal Speed Advisory (GLOSA), Traffic monitoring using Probe vehicle data and Smart Routing.

Getting used to the C-ITS will allow the NRA to be prepared for the future challenge of Automated vehicles.

1. V2I

Implications for NRAs

By deploying C-ITS solutions, through V2I information exchange, the Road operator will be able to get more data with services such as Probe Vehicle Data (PVD) that will provide him important data such as speed and position of the vehicle.

2. I2V

Implications for NRAs

By deploying C-ITS services, through this I2V information exchange, the road operator will be able to act on the traffic by sending information directly to the car through services such as:

- Road Works Warning (RWW): Allows a road operator to provide information through I2V communication to approaching vehicles about conditions at a work zone ahead. GLOSA: thanks to I2V communication, GLOSA is a traffic service allowing the driver to adapt its driving according to the state of traffic lights.

3.6 Role of the NRA (type of ownership)

CAVs have the potential to radically alter traditional business cases of, for example, private vehicle ownership or pubic transport based on fixed routes and timetables, and so this should be an area of focus for the NRAs. E.g. the AV Living Lab offers business development and hackathons to actively encourage this, however none of the sites described any new business models that were being considered so far.

One potential new business model will be around insurance, potentially moving away from privately held vehicle insurance, to corporately held insurance for fleet CAVs for example. Two sites (AV Living Lab and CityMobil2) reported that they are insured in a conventional manner. ConVEx, which is a site that provides data to physical trials say that insurance details are shared across their platform, whilst Transpolis has an insurance company as a shareholder in the site and is developing the capacity to conduct tests around this.

From the test site operators' point of view, they expect benefits in the collaboration with the NRA on:

1. Gaining knowledge of the NRAs networks, vision of the future and available resources
2. Ensure close and safe test environment to public road testing
3. Automated driving legislation, GDPR, privacy,
4. Assurance of legal framework and legal viability, infrastructural adaptations
5. To facilitate the following CAV equipment and services: GNSS correction data (for vehicle localization with high accuracy), HD maps, dedicated communication networks (for example ITS-G5), sensor networks (for example CCTV) and a data management and control centre (similar to a TMC).
6. Transpolis S.A.S. aims at being a certified tests site by the French ministry of transportation (public and private highways) and cities

7. Scope of work includes necessary adaptations in road infrastructures, road equipment, and in vehicles
8. Knowledge and understandings will inform future policy for CAV related infrastructure. The key aim is to improve safety and reduce congestion and so improve customer experience.

Already identified in STAPLE Deliverable D3.1 there exist several roles of the NRAs in relation to the test sites:

- **Partnership**, contractual partnership (ALP.Lab, ZALAZone)
- **Collaboration** and Integration with the Innovation Centre, the testing facility of the Dutch Road Operator RWS
- Strong **cooperation** with the Greek Ministry of Transport to define the legal framework and ultimately conduct the demonstration within the city road tissue.
- Based on **Projects** (such as C-Roads) for research & industrial applications perspective: TRANSPOLIS
- **Agreement** with FMOT on homologation of CAV equipment and systems – ongoing activity: TRANSPOLIS

Three of those test sites who do not have any relationship with the NRAs expressed their interests to have one, those were Aldenhoven Testing Center in Germany, AV Living Lab in Slovenia and Catalonia Living Lab in Spain.

3.6.1 Shareholder

As a shareholder the NRA is a full partner of a test site (e.g. Test Pilot A2-M2 Connected Corridor). Accordingly, this is the strongest relationship between the NRA and the test site. Depending on the ownership of the NRA and the remaining partner of the test site resp. the organisation type of the test site itself there are several constellations. This becomes especially relevant in case either the NRA or the test site are public bodies.

Implications for NRAs

As a shareholder NRAs can generate the highest impact. They get full information and insight to all tests performed at the site. This also includes non-public tests, which are usually performed by industrial players to keep company and development secrets.

As shareholder the NRAs can decide on the direction and focus of the tests and the continuous adaptations and development of the test site. As an example, to keep the digital and physical infrastructure as a key element for automated driving. Such an approach makes testers aware of the opportunity's infrastructure can deliver and in the same way create awareness about the related costs and efforts for the NRAs in case of a roll-out of the tested approach.

Furthermore, as stakeholders NRAs are in the best position to sell their available functionalities and competences, which can become a business case at least for the tests.

The drawback of becoming test site shareholder is the related financial investment and the financial risk involved with test site construction and operation.

3.6.2 Contractual partner

In this case, the NRA has a contract that connects them as an associated partner to the test site organization. Typical examples are ALP.Lab and ZALAZone.

Implications for NRAs

The advantage of this relationship is that it is quite flexible as all collaboration rules can be defined in the contract. These rules can be about regulations on using NRA operated roads as part of the test tracks, using data collected by the NRAs at the test site, using data collected at the test site by the NRA, testing procedures, exchange of experience and the relation to test site external players including project/test acquisition and public awareness raising and public relations activities.

It is key for NRAs that, similar to the advantage of being a shareholder above, become access to information and experience collected at non-public tests to enable to derive according insights. One must consider that such tests can be performed within the test site but at road sections not under the control of the NRA (e.g. at dedicated test tracks).

Of course, the steering ability on the direction of the test site itself becomes limited compared to the NRA role as shareholder. This comes with the benefit of a reduced, limited or even no financial risk.

3.6.3 Project related partner

For this role of the NRA one must distinguish between several relations of the project to the test site.

a. The test site itself is project. This means that there is a defined start and end date, planned costs including potential funding as well as a task and responsibility plan. As such a test site is per definition of limited time, there should be a very well test case that will be analysed by such a project. All the costs for establishing the test site must be justified by this test case compared to a long-lasting test sites that distributes the costs over the years and tests.
b. The project is about the development and assembly of the test site, which is planned to be continued afterwards.
c. The project includes tests performed at the test site.

Implications for NRAs

a. In this case the NRA, as project partner has a dedicated role defined in the project plan. Of course, all rules, responsibilities, as well as the expected outcome are pre-defined. Hence all benefits, costs and risks are pre-defined. The highest benefit is in the well-known risks. The disadvantages are that due to the limited amount of time only a limited set of tests can be performed.
b. In this case there must be a clear plan on how to justify the costs for the NRA with the intended test and business cases of the test field. The advantage for the NRA to become project partner is that they have high influence in the setup and the according direction and focus of the future tests at the test site.
c. In this case the test site is only a facilitator to enable certain CAV tests. The NRA as project partner has the opportunity to use the test site as all other project partners and can derive insights according to the project plan.
   It is worth to mention that especially this NRA role can be mixed with another test site related role of the NRA. Typically, this happens when the NRA is shareholder or contractual partner of a test site and at the same time is project partner of a project performing test at this test site. One must clearly distinguish between the responsibilities of the NRA at the different roles (as test site partner and as project partner). On the other hand, the concurrent role could also lead to an efficiency gain and a win-win situation for the test site as well as the project.

3.6.4 Road provider

As there is an obvious need for a contractual relation between the test site and the NRA this role is a specific case of the already described 'Contractual partner' role in section 3.6.2.

Implications for NRAs

In this case the NRA is only road provider. It has still to ensure no harm of other road users, guarantee maturity and reliability of the automated vehicle as well as a test and test approval procedure that covers all safety relevant aspects.

As the NRA in this case is not involved in the evaluation and analyses there is only a financial benefit. Accordingly, there must be a clear business case behind such an NRA role. Otherwise other forms of contractual cooperation should be aimed at.

3.6.5 No direct relationship / Stakeholder

In case the test site has no direct relationship, the NRA is just considered as a stakeholder. Out of the questionnaires it becomes clear that still these test sites are still very interested in the contact to the NRAs for information and knowledge exchange.

Implications for NRAs

Of course, this is the weakest kind of relationship. Still NRAs should have a look at such sites and keep in contact if there is potential to get insights. Of course, there is no option to steer the direction and focus of the tests and the continuous adaptations and development of the test site.

3.7 Regulatory framework

Deployment of connected and automated driving needs to be viewed also in the legislative perspective. Legislation tends to lag technology developments as it is hard to put exact dates to envisaged milestones in the development process. Ambitious technological goals might not be met completely and alternative developments in other related fields might require changes to the initial schedule[13]. According to the EU Committee of the Regions policy makers need to face the regulatory frameworks which:

- Follows technology developments quite closely – belated attempts to regulate CAVs bear serious risks related to safety and public acceptance and might hinder technological progress
- Take the implications of the operation of automated and non-automated vehicles into account
- Respect environmental standards.

Following regulatory and policy related impacts are envisaged with respect to CAVs deployment by issue (based on EU Committee of Regions).

Policy Issue	Level	Implications for CAVs
Road traffic act	national	Stepwise integration of CAVs into the road traffic act. Correct use of assistance systems in Levels 1

[13]State of play of connected and automated driving and future challenges and opportunities for Europe's Cities and Regions, the European Union and the Committee of the Regions, 2018.

		to 3 In Levels 4 and 5 the driver no longer exists – thus clarification who is in charge to ensure that vehicle is operating safely.
Enforcement of traffic rules	national	In theory Levels 4 and 5 would allow for in-built enforcement.
Driving licence	EU, national	Step by step integration of CAVs into driving licence education in stages 1 to 3.
Other legal matters	national	At those stages where no driver would be required new safety concerns might come up e.g. children using services who would not be allowed to do so; errors in language recognition in case of on-demand services leading to legal disputes; wrong reaction patterns in case of dangerous situations e.g. in deprived urban neighbourhoods.
Road maintenance and operation	EU national regional local	Traffic signs and road markings will eventually need to comply with strict international standards (causing liability risks in case of non-compliance). Electronic car – infrastructure communication: relates to questions of data privacy (use of data generated for public and commercial services) and cybersecurity (liability risks).
Environmental standards for vehicles	EU national	The development of energy-efficient alternative drive (engine) technologies is not necessarily connected to development of automated systems but current car manufacturers are leading in development – thus disruptive developments in engine technologies might be delayed.
Environmental regulations	national regional local	One can expect that urban mobility will be shaped increasingly by regulations stemming from environmental aspects: In order to decrease urban air pollution regulations e.g. toll systems driving bans for certain vehicles will become more widespread in the centres of growing agglomeration areas; CAVs is thus challenged by the parallel development of alternative drive technologies.
Tax and insurance	national	The regulations on taxes and insurances are decisive for cost of operation thus also for vehicle ownership and mobility patterns. CAVs needs to consider the aspect of liability with an increasing role of the system producer

		from Levels 3 to 5. Taxation on cars tends to favour new cars and alternative drive technology (currently e-cars) in many countries in order to foster quicker turnover in the car stock; thus, one can assume that tax incentives for the purchase of automated state-of-the-art vehicles might be introduced.
Business regulations	national	New services based on CAVs might challenge existing business regulations.
Ethics	EU national	At Levels 4 and especially 5 the machine takes over decisions of actions in a real-world environment with potentially far-reaching consequences (e.g. in cases of an unavoidable crash). Therefore, ethical questions arise that must be provided for in the behaviour patterns of the machine.

Table 1: Regulatory issues regarding deployment of CAVs.

With a wide-spread availability of Level 3 systems, a focus will probably have to be on the precarious and accident-prone driver/machine-interface. Wide-scale introduction of fully automated Level 5 systems will trigger far-reaching changes in the legal framework.

With Level 4 and 5 systems, humans will not be responsible for driving the vehicle anymore. Therefore, liability in case of accidents will have to be taken over by other players in the system like car manufacturers, software developers, traffic control systems, car owners (like municipal transport companies) or road infrastructure managers including NRAs; the latter in case of accidents caused by defective infrastructure (e.g. unreadable/wrong road signs or road markings). Currently, the liability issues connected with Level 5 connected and automated mobility (CAM) are under discussion and unsolved.

Regarding deployment of connected vehicles (CV) data protection mainly concerns the data exchange between the car and its surroundings. The communication can take place with road infrastructure, traffic control systems, other cars and road users, the car manufacturer, public authorities etc. Three main aspects can be mentioned here:

- cybersecurity
- data access
- data privacy

Concerning cybersecurity, CAVs provide many potential entrance points for hackers or malware. This holds true for the car-infrastructure communication, too. Especially considering the car-based hackers attacks in the past years, there is a considerable security risk and therewith liability risk that might also hit the infrastructure manager (NRAs). In any case, costs for cybersecurity measures will arise.

Data privacy concerns access and protection of data gathered from publicly accessible CAVs systems and infrastructure. On the one hand, there is considerable business potential as well as information interest of public bodies requiring access to data generated by CAVs. On the other hand, data privacy requirements like user consent to data sharing must be complied with. When the introduction of CAVs is imminent, it is worthwhile considering setting up guidelines or an information point at EU level supporting NRAs on the issue.

For the proper functioning of CAVs systems, data access of road infrastructure managers (NRAs) to required data gathered by other players (and vice versa) must be secured, an important issue for NRAs running traffic control and management systems. The issue of data access is also crucial for a level business playing field and fair competition, e.g. for independent repair shops. Legal measures therefore must balance the requirements of fair competition, requirements of public bodies and protection of personal data.

Finally, the introduction of CAVs requires increased standardisation and interoperability of road infrastructure, e.g. traffic signs, road markings, traffic control systems, potentially high costs for upgrading of local and regional road infrastructure according to the new standards will come up.

According to the US National Highway Traffic Safety Administration (NHTSA)[14] the following best practices for state legislatures regarding automated include:

- Provide a “technology-neutral” environment
- Provide licensing and registration procedures, including insurance.
- Provide reporting and communications methods for public safety officials.
- Review traffic laws that may serve as barriers to automated driving operation.

The key Strands related to legislation of CAV driving according to the UK’s Zenzic Roadmap[15] include:

- Legislation for clearing road space for automated vehicles (HW17): The establishment of Baseline policy and standards (LR05), realised towards the end of 2022, is a key enabler of this. The first set of Stable standards and regulations now in place in UK (LR66) will be delivered by the end of 2029.
- Harmonised vehicle approval scheme established (LR57): The establishment of a harmonised and holistic approval scheme for self-driving vehicles is a vital major task. All but one Milestone in this Strand come from the Licencing and Use and Vehicle Approvals Streams. This Strand begins with the Law Commission review into automated vehicles (LR09), and subsequent Law Commission final report (LR10) in 2022 (Law Commission, 2019). A Vehicle approval framework for self-driving vehicles (LR48) leads to a small-scale national type approval process (LR47), National vehicle approval scheme (LR70) and ultimately a certification methodology in place for CAM (LR52).
- Appropriate update cadence established (LR74)
- Highly automated vehicles are more easily able to be on public roads legally (LR30) This Strand is a contributor in achieving the key deliverable of a world-class legal and regulatory framework that promotes and enables CAM to be deployed at scale. Milestones feed into Adapting regulation for highly and fully automated vehicles (LR36), which leads to further Regulation change(s) to allow self-driving vehicles to be used for services (LR39) by the end of 2024.
- Partially simulated certification in use (LR53)
- Digitisation of rules of the road (The Highway Code) (LR71): It is expected that connected and self-driving vehicles use a digital version of The Highway Code – the rules of the road. This would ensure vehicles obey traffic orders and follow restrictions placed upon them in certain locations and times.

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[14] Legal Issues Related to the Development of Automated, Autonomous, and Connected Cars, Jones Day White Paper, November 2017.
[15] UK Connected and Automated Mobility Roadmap to 2030, Zenzic, 2019.

Legislation readiness for deploying automated driving for CEDR funding[16] countries is presented in Table 2 below (based on KPMG Autonomous Vehicles Readiness Index[17]).

Country	**AV Legislation readiness/advancement**
Netherlands	Leading country, working with neighbours to adopt automated vehicles technology for freight, with a plan to launch platoons of more than 100 driverless trucks on major routes from Amsterdam to Antwerp and Rotterdam to the Ruhr valley. It is introducing new laws that will encourage automated vehicles. Dutch government is taking an active role in automated vehicle safety and legal issues, with the infrastructure minister announcing a 'driving license' for self-driving cars (March 2019) and truck platooning in 2018. The ministry also announced a legal framework for autonomous driving. The *Experimenteerwet zelfrijdende auto* (law governing the experimental use of self-driving vehicles) was approved by the Parliament in 2018. It allows experiments with automated vehicles on public roads without drivers in vehicles, although they must be monitored remotely.
Ireland	At present the law requires that the motorist be in charge, and responsible, for the vehicle. The latest systems on sale with new cars allow for some braking and steering functions to be operated by the vehicle's software, through features like adaptive cruise control or lane-keeping assist. So far, any testing in Ireland has been done on private land or via simulators. But there is a significant hub of research in the west of Ireland ready to take advantage of any changes. For example, Jaguar Land Rover recently opened a major research facility in Shannon. A proposal to allow public roads to be used to test self-driving cars was considered by the Government on Dec. 6, 2019. The legislation will seek to redefine in law the term driver so that autonomous vehicles can be tested on Irish roads.
Norway	The country legalised automated vehicle testing on public roads in January 2018, giving clarity for providers and leading to trial bus services in several locations. The NRA has been testing automated truck platooning in the north of Norway.
Austria	Austria joins with Hungary Slovenia to create a 'driverless region' as its automated vehicle companies develop international links. In March 2018, joined in agreeing establish cross-border development testing of new vehicle technologies including automated vehicles, through Austrian-Hungarian-Slovenian region. Within the scope of the first Automated-Connected-Mobile Action Plan (2016–2018), Austria has established a legal framework, and test environments and a variety of research projects have been started
Sweden	The country has plans to introduce legislative changes likely in July 2019 that will allow automated vehicles on public roads and tests without human drivers. The transport agency has already permitted small-scale automated vehicle pilots. These include a driverless bus service that started running on 1.5km section of public road in northern Stockholm in January 2018 which is free to use and have an

[16]CEDR funding countries of this call include: Austria, Finland, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden, UK.
[17]Autonomous Vehicles Readiness Index, KPMG, 2019.

	emergency human driver. Sweden has one of the highest government readiness for automated vehicles.
Finland	Finland is exploiting its cold climate through research on how automated vehicles can handle icy roads and tracks. In December 2017, government research organization VTT technical research centre of Finland (VTT) showed its robot car Martti driving autonomously on a snow-covered road, and the project team has since added 5G technology to the vehicle. Swedish truck maker Scania trialling truck platooning in icy conditions, and a 5G network established in the northern town of Oulo that allows organizations including VTT to test applications such as automated vehicles. The government has recently passed two new laws that enable automated vehicles. The Transport Service Law opens taxis to competition, allowing ride-hailing services to gain access from 2020, and permits someone to control a vehicle remotely. The Road Traffic Act will integrate detailed location data on roads, signs, traffic lights and other control mechanisms for automated vehicle operators to use, and is set to repaint the continuous yellow lines on Finnish roads in white, partly as these are easier for machines to detect.
Germany	Since 2015, the German government has followed a national automated vehicle strategy and has recently started working to ensure that automated vehicles are used ethically, including protecting people rather than property or animals. The legal requirements for the use of the first highly automated and fully automated driving functions for regular operation in road transport have been in place since 2017. Several of Germany's powerful states are also working on automated vehicles. North Rhine- Westphalia, which includes Cologne and Düsseldorf, has established a Zukunftsnetz Mobilität (future of mobility) network to support municipalities, 64 with the promotion of automated vehicles among its tasks.
UK	The UK continues to be a leader on policy and legislation. In August 2018, the UK Parliament passed the Automated and Electric Vehicles Act, which adapts the existing motor insurance framework by extending compulsory insurance to automated vehicles as well as the driver. In November 2018, the government announced support for three public trials in 2021, including buses with automated vehicle technology across the Forth Bridge in Scotland and self-driving taxis in London. Cross-government collaboration has also been effective. For instance, the Law Commissions of England and Wales and Scotland are currently reviewing the UK's legal framework for automated vehicles, due to be completed in March 2021. Improving consumer acceptance will be critical for the deployment of automated vehicles. To achieve this, government and industry have a role to play in communicating the benefits of automated vehicles and the efforts being taken to ensure their safety. Rigorous testing and the publication of safety standards — such as the new cyber security standard for automated vehicles, was published in December 2018.
Slovenia	The Ministry of infrastructure is aware of the immediate future impacts and thus fully endorses and supports the development of autonomous vehicles in Slovenia. The digitalisation and decarbonisation are key aspects of future mobility solutions that will be safe, efficient,

	environment-friendly, and sustainable. Advances in C-ITS and e-mobility are the main paths towards solving the transportation congestion issues, changing mobility habits, and lowering vehicle emissions. In Slovenia they developed a living laboratory, called BTC City Living Lab. It is the focal point of innovation energy and acts as a testing and demonstration facility, creating new solutions that will enhance the existing and create new business models. BTC City Living Lab was created in 2018.

Table 2: Automated vehicle legislation readiness for CEDR funding countries.

The **UK** has set up a government department, the Centre for Connected and Autonomous Vehicles, and is working on legislation to allow testing on motorways in the country. There are also testing schemes in cities, including London and Coventry, with research organizations established to develop the technology and systems. The recently updated Code of Practice for Automated Vehicle Trialling provides welcome further clarity on what is expected of organizations wishing to test autonomous vehicles on UK roads.

'It remains the responsibility of those carrying out trials to ensure that their trials comply with all relevant legal requirements. The difficulty arises when those legal requirements, which were not developed with autonomous vehicles in mind, are contradictory with their operation. This is why the Law Commission of England and Wales and the Scottish Law Commission are undertaking a review of the legal framework on behalf of the UK Government's Centre for Connected and Autonomous Vehicles.'

In **Germany**, the Autonomous Vehicle Bill was enacted in June 2017, modifying the existing Road Traffic Act defining the requirements for highly and fully automated vehicles, while also addressing the rights of the driver.

The bill defines what a highly and fully autonomous vehicle is and states that such technology must comply with traffic regulations, recognise when the driver needs to resume control, and inform him or her with sufficient lead time as well as at any time permitting the driver to manually override or deactivate the automated driving mode.

Currently, autonomous testing legislation is handed out by city regulatory authorities. Some have approved pilot fleets operating on private property that serve as an example of wider adoption, including shuttle services interacting with pedestrians and bicycles. However, the current federal government plans to create an infrastructure suitable for Level 5 fully autonomous vehicles by the end of the legislative period. Germany also aims to expand autonomous vehicle testing on the autobahn beyond the A9 highway in Bavaria, where it is experimenting with vehicle-to-vehicle communication via 5G mobile networks.

France is establishing a legislative framework that will allow the testing of autonomous cars on public roads in 2019.

Level 4 vehicles, those with almost total autonomy, will be used on roads around the country with no human operator behind the wheel, as the current legislation requires. Currently, only certain companies can test driverless vehicles in the country, and while these are conducted on public roads, this is heavily restricted to time and location, to ensure there is no risk to ordinary members of the public.

The French Government is supporting the development of self-driving cars, with the aim of deploying 'highly automated' vehicles on public roads between 2020 and 2022.

More than 50 autonomous-vehicle test projects have taken place in France since 2014, including robot taxis, buses and private vehicles. The government has made €40 million available to help subsidize new projects.

3.8 General findings

On top of the already identified results in the previous sections there are general practical learnings out of the test sites investigated:

- At most of the test sites there are demonstration tests and private tests. Demonstration like tests are mainly for public relations. Private tests are the ones where novel features and functionalities are tested. At such tests data, results and even coarse insights are kept secret. Even for the test sites themselves it is difficult to collect relevant data. They are just test space / environment provider.
- In the same way OEMs are reluctant with sharing data the same is for test sites. Data is considered as the new oil. Consequently, NRAs should focus on getting at access to this information. This could be a return service for providing access to NRA roads or by any other contractual agreement.
  To improve this situation, it is key to establish trustful cooperation between NRAs, the test sites and the OEMs. An initiative could be to create contract templates that can serve as a base for such a cooperation.
- As most of the test sites provide physical test environments, they are not dedicated to specific automation levels. Many test sites cover all SAE levels or have the potential to host testing activities on automated driving systems on the higher levels of automation.
- Many test sites also provide communication and data exchange infrastructure enabling also test related to these functionalities.
- On top of that some provide HD maps and simulation environments that enable simulation in the loop (SIL) and hardware in the loop (HIL) tests.
- There is little interest in operating a test site as a business case for NRAs. At least no test site reported financial benefits for the NRA for offering road site beside covering costs for data provision and securing / safeguarding the test case.

3.9 Summary of practical learnings

Out of this analysis there is no single prototype of a CAV test site. They differ in testing environment (highway, urban, interurban), type of facility (open and closed tracks, off-road trial, data trials and simulation trials), use cases covered (e.g. highway chauffeur, platoons and HD mapping), priority areas (safety, traffic efficiency, ...) and role of NRA at the test site (shareholder, stakeholder, road provider, ...) and many more like size, additional infrastructure and facilities.

Typical features of test sites are that they deliver at least open and/or closed road-testing facilities and potentially data and simulation related facilities. They usually cover all SAE levels or have the potential to host testing activities on automated driving systems on the higher levels of automation.

The considered use cases show that there is a huge potential for savings and efficiency gains for NRAs either by potential reduction of infrastructure, higher fluidity and harmonization of the traffic or reduced human workload. All priority areas of the NRAs can benefit from road safety, traffic efficiency, customer service as well as maintenance and construction.

At some stages of the CAV development an infrastructure supporting automation functions will be required. In case such a CAV ready infrastructure is requested by the customers (drivers of the CAVs) not only on highways but also on interurban roads this comes with huge investments. NRAs need to become aware of such a potential situation and prepare and align roadmaps to avoid these investments.

Special emphasis of the NRAs should be paid to the connected and cooperative part of CAVs. The deployment of V2I/I2V and V2V communication, also known as C-ITS has the potential to bring many opportunities for the NRA in general and more specifically the road operators.

NRAs should become aware of the data related infrastructure requirements for automated driving. This is for the data exchange (road site units, mobile communication, fibre optic networks) as well data storage and high-performance computing facilities.

Data collection is an essential part for the development of automated driving due to the need of huge amount of data for all the learning techniques used in automation. The key is to provide the most realistic as well as relevant data.

Regarding the regulatory framework one must consider that legislation tends to lag technology developments. According policy makers need to face the regulatory frameworks which follows technology developments quite closely take the particular implications of the operation of automated and nonautomated vehicles into account and respect environmental standards. This becomes a huge task also for NRAs to keep their interests respected in the upcoming regulations. So far, a lot of national regulation activities take place which need to be harmonized at the European level as soon as possible.

One of the key questions for NRAs is their relation to test sites. Several options have been identified from a simple stakeholder role, up to a pure road provider, project related and/or contractual partnership up to a shareholder of the test site. Out of the 39 identified test sites there are examples for all these roles of the NRA. Even in case there is no direct relationship between the NRA and the test site, these sites are very interested to establish a connection. As a general rule, one can derive that the stronger the relation between the NRA and the test site, the NRA benefits in terms of data and information access, insights collected as well as the ability to steer the direction and focus of the test site. This comes with the price of financial risk involved with the test site investments and operation. At least no test site reported financial benefits for the NRA for offering road site beside covering costs for data provision and securing / safeguarding the test case.

4 Impacts of different test sites

In this chapter of the deliverable our learnings of the impacts (general, economy, employment, workforce, and the core areas of NRAs), including socio-economic impacts, are provided. In each section, a review of the literature is used to introduce the topic, with an emphasis on socio-economic impacts which is then followed by specific impacts of test sites on NRAs responsibilities. As outlined in Figure 4 below, the impact assessment will be based on practical learnings and knowledge gathered during the interviews and test site visits. A review of relevant literature on the topic of the socio-economic impacts of CAVs in general was undertaken to sort out the impacts mostly relevant for the NRAs operations such as for instance cost savings related with automated maintenance work and inspections, potential changes in the structure of organisations, and new jobs and competencies that are needed.

The literature review covers impact of CAVs to discuss such impact aspects as:

- Economy, employment and workforce: e.g. new jobs and competencies the NRAs need to consider with the connected and automated driving becoming a near future reality.
- Road Safety: e.g. road safety, passenger/driver health.
- Traffic efficiency: e.g. travel behaviour impacts.
- Customer service: traffic information (incl. smart routing), security of data, cybersecurity data access and privacy, user satisfaction.
- Maintenance and construction: e.g. cost efficiency: construction and maintenance, road network operations, asset management, CO_2 reductions.
- Cooperation services / C-ITS: e.g. automation and infrastructure readiness level.

At the end of this chapter, we provide an in-depth account of a series of relevant case studies are presented to enhance the level of quite low response rate during the stakeholder survey and interviews. The case studies cover construction and maintenance aspect of CAVs including a pre-marking robot used in the UK, Transpolis test site, Zenzic information on cyber security and the ENSEMBLE truck platooning project. Another case study cover truck platooning and the last one an urban scenario or another highway speed scenario (subject to discussions and data/ test site availability and cooperation).

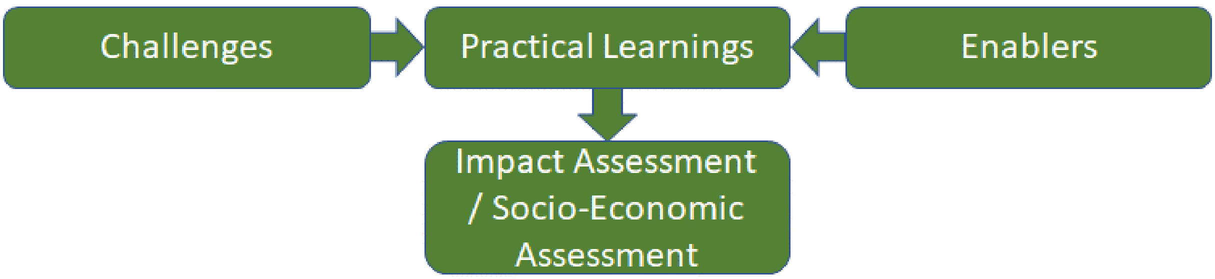

Figure 4. Methodology for the impact assessment.

4.1 General impacts

The expected large-scale introduction of automated driving features on public roads are expected to influence the whole transport system and thereby transportation stakeholders including NRAs. Furthermore, this introduction will influence beyond transportation, as some changes will have critical impacts that affect throughout the whole of our society. It could for instance be through new jobs, as have been evident throughout history with the addition of new technology, or how the effects of automated driving technology distribute between members of the society. As was defined in STAPLE deliverable D3.1, and further discussed in the previous chapter, the NRAs can have different roles in different test sites. Furthermore, the implications as discussed in chapter 3 impact the work of NRAs.

4.2 Impacts on economy, employment and workforce

4.2.1 Economics and work force

There are concerns that autonomous vehicles will take jobs in the construction industry, but this needs to be put into context. David Autor, during a TED talk on automation[18], points out that during every industrial revolution, whilst technical progress has threatened to replace jobs, for example, tractors substituting manual labour, assembly lines increasing production, computers taking over bookkeeping, employment has increased. Despite this technological progress replacing jobs, the fraction of US adults in the employment market was higher in 2016 than in 1890. Employment in agriculture in the European Union has halved[19] from over 9% of total jobs in 1991 to 4% in 2019. In 2013, the proportion of jobs in agriculture in the UK dropped below 1%[20] for the first time, whereas it was around 20% in 1841, yet this is not reflected in unemployment figures, as these jobs have been replaced by jobs that didn't exist before. As Autor states "As automation frees our time, increases the scope of what is possible, we invent new products, new ideas, new services that command our attention, occupy our time and spur consumption". So, whilst some jobs in transport will be lost, others will replace them. The following section considers the impact of automation and potential skills that will be required in the future.

A 2017 report by the McKinsey group[21], identified that globally, construction sector labour productivity has increased by around 1% per annum over the past two decades compared with 2.8% globally and 3.6% for manufacturing.

Automated driving features varying degrees of automation are successively brought to the market by manufacturers and as they become more accepted the deployment rate among users will increase. Studies on the social and organisational effects of increasing automation on freight transport and transport logistics from a systemic perspective are still largely absent. In particular, the effects of automation on road and rail freight transport and the distribution of transport performance between these two modes of transport are yet to be determined through research studies. The impact analysis regarding the expected change in transport costs, transport time and transport quality due to different automation tendencies in the individual components of the transport chain shows that, whilst automation will develop at different speeds per component and, the effects to be achieved per component may vary.

A study by the Organisation for economic co-operation and development (OECD) from 2018 assumes that the probability of losing a job through automation is 49% across all job profiles in Austria. Other studies assume less drastic effects and see Austria rather in the middle field

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[18] https://www.ted.com/talks/david_autor_will_automation_take_away_all_our_jobs/transcript?language=en#t-470638
[19] https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=EU
[20] https://www.independent.co.uk/news/uk/home-news/less-than-1-of-british-workers-now-employed-in-agriculture-for-first-time-in-history-8645324.html
[21] https://www.mckinsey.com/~/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/Reinventing%20construction%20through%20a%20productivity%20revolution/MGI-Reinventing-Construction-Executive-summary.ashx

about employment shares and the possibility of automating jobs. There is relative agreement that qualification profiles will increase and that poorly qualified people will be affected by a changeover. At the same time, new jobs will be created by the changed processes, especially with a focus on control, monitoring and coordination. Interesting thought processes assume that new job profiles will emerge in the future, such as robot coordinators and algorithm insurers. However, one does not necessarily have to look far into the distance, as mechatronics engineers, electricians and other skilled workers are already in great demand.

Especially in the area of highly automated driving, there is a lot of uncertainty as to what extent personnel will still be on board and which activities will be carried out automatically. In some areas, a changeover to automated operation will take several years, and in the meantime, there will be a need for action about the alignment of differently automated transport chain components. A major potential of automation in the social sector is occupational safety, which will increase significantly in many areas. Not only will safety at work increase, but also physically stressful work processes and unfavourable working time regulations will decrease. In general, it was found that the need for personnel is decreasing due to a decrease in manual activities and a small number of but better trained employees. An increased need in the area of control and monitoring also creates jobs, which in most areas is only a slight decrease. The only significant reduction in personnel is in the handling of load carriers for onward transport and in vehicle maintenance. There is hardly any effect on personnel requirements in the areas of load securing, the journey to the recipient, the acceptance and collection of goods/goods and the handling of accidents. More personnel will be required to prevent people from deliberately obstructing vehicles.

Increasing automation has a positive effect on occupational safety in most areas. A slight increase in occupational safety can be expected in the case of intermediate storage/repacking, the transition from the warehouse to the transport unit/carrier, load securing, the actual truck journey and the automated journey to/from the connecting railway. Strong improvements are seen for the transport to the raw material supply (internal), the journey from the completed production to the warehouse, the coupling of trailers/semitrailers, the train treatment, the brake test and clearance check before departure.

Working hours are unchanged for many transport components even with increasing automation. Slight decreases occur during loading of the load carriers, the trip to the terminal, the trip in the terminal, the handling of the load carriers in the intermediate storage and the handling of the load carriers for further transport. A slight increase in working time is expected for the actual truck journey (need for control personnel) and the automated journey to/from the connecting railroad, since automation will affect the driving time regulation through passive driving.

An (at least slight) increase in the necessary qualifications is to be expected for all transport chains. Retraining in control and monitoring as well as IT skills are on the agenda. Due to the lower personnel deployment in areas, a better qualification of the remaining personnel is inevitable. There will be significant changes in the areas of interim storage/repacking, travel from the warehouse to the transport unit/carrier, load securing and travel from the terminal/hub to the delivery address.

In the UK, a PwC analysis (2017) predicted that 56.4% of jobs in the transport and storage industry (currently employing 4.9% of the total workforce) would be at potentially high risk of being automated by 2030. At the same time, it seems possible that automation will not progress as quickly as this, as there are regulatory, organisational and legal hurdles that slow down this development. Negative developments due to the elimination of job profiles are countered by cost savings. 168 billion dollars are to be saved annually on truck journeys in the USA in future (Solon 2016). Of this amount, $70 billion will be saved through the loss of jobs, $35 billion through greater fuel efficiency, $27 billion through increased productivity and $36 billion through fewer accidents (Solon 2016). At the same time, there are studies that assume that income will fall by around 200 billion dollars, which would significantly reduce purchasing power.

Millonig and Shaheen[22] discussed the implications of CAVs on economics and workforce. They noted that the massive and wide-ranging take-up of CAVs is likely to spur the development of a variety of new business models, mostly from the private sector, which may in turn affect many professions in the transport sector (e.g., maintenance, traffic management). They remarked that the diversification and flexibility of CAV services will lead to increased individualization and personalization, thus offering new opportunities for start-ups, although the market may ultimately be dominated by a limited number of global actors.

ICT skills will be increasingly demanded in the future. CEDEFOP (2016)[23] highlights the increasing land transport sector dependency on ICT-based and specialized equipment and products. Thierer and Hagemann (2015) also emphasize the need for ICT skills in addition to the traditional vehicle repair skills. In this context, a shortage of ICT professionals has been identified for 2020 (European Commission, 2016b). If the demanded skills can be matched in the future, there could be opportunities for reallocation of employees. For instance, Thierer and Hagemann (2015) claim that in the future some highly qualified mechanics might move over to higher-paying jobs in the information sector. ITF (2017) also postulates that skilled and experienced drivers could be demanded in the case that remote control rooms are installed for CAVs monitoring.

4.2.1.1 **Cost efficiency**

Improvements in efficiency induced by automation and specific processes being taken over by robots and automated vehicles suggest that changes in mobility patters could be anticipated. The introduction of CAV services could influence the availability, cost, and efficiency of mobility services with an associated impact on local, regional, and national prosperity. The ways in which CAV services are deployed and operated may have differential impacts on how the benefits of automation are distributed. Automation of driving can therefore increase the efficiency of transport by providing safer, more reliable transportation. However, task automation is typically associated with a reduction in the number of employees and/or the training required to deliver that task. This is especially true when an employee represents a significant element of the operating costs for that system.

Automation of the driving task is attractive for the industry to reduce the economic cost and physiological constraints (e.g., fatigue) on freight operations. Thus, truck platooning provides some promises regarding cost efficiencies but also creates some externalities in terms of potential challenges for infrastructure operators (may contribute to rutting, safety of other vehicles in the traffic mix). Real-world trials of truck platooning in Europe have taken place with vehicles from manufacturers such as Daimler, Volvo, Scania, and DAF participating. For example, convoys of trucks from each manufacturer completed journeys from different parts of Europe, converging on the Dutch port of Maasvlakte. Drivers were present in all trucks but only the lead vehicle was fully driven by a human driver. Electronic connections between the lead truck and following trucks managed acceleration and braking to enable closer following distances. Such demonstrations have shown real-world improvements in fuel efficiency of 8%

[22]Millonig, A., & Shaheen, S. (2018). Socioeconomic Impacts of Automated and Connected Vehicles, Connected and Automated Vehicles and Travel Behavior Impacts, Washington, DC: The National Academies Press. https://doi.org/10.17226/25359
[23]CEDEFOP, Automotive sector and clean vehicles, Analytical Highlight, EU Skills Panorama 2014, 2014, Retrieved April 2018 from: http://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_Automotive_0.pdf

(Chan et al. 2012[24]). To maximize the opportunity for platooning to take place, it will be necessary to achieve multi-brand platooning where trucks from different manufacturers can platoon interchangeably, such as with the ENSEMBLE project. The introduction of automated vehicles to the freight industry has caused concerns about job losses: the role of human truck drivers will be taken by automation technology (Beede et al. 2017[25]). In the longer term, when automation may play a greater role in the movement of goods by road, the transition away from truck driving as a common form of employment may be effectively managed.

This may include roles in managing operations from regional control centres and a range of different tasks associated with the maintenance and management of automated delivery vehicles. If automation can be proven to manage long periods of highway driving safely and efficiently and if the workplace environment for the driver can be made acceptable (toilet facilities, refreshments, connectivity etc.), it may be possible to lengthen the operating window for truck operations leading to increased delivery.

4.3 Impact on NRAs core areas

4.3.1 Road safety

Safety: road safety, passenger/driver health

Traffic safety benefits are a fundamental motivator for CAVs development and deployment. More than 90% of traffic accidents are estimated to be caused by human error[26]. CAVs are expected to mitigate accident risk stemming from human error with the potential for significant societal benefits. Evidence of the safety benefits are still being gathered, primarily through public road testing of the vehicles taking place in EU Member States and in the US.

Not only may CAVs mitigate some errors, but also, they may introduce new types of driving and vehicle operation errors. As with CAVs, shared mobility operations have the potential to both mitigate and exacerbate traffic accidents caused by human error. In terms of the former, shared mobility operations could provide alternatives to driving for some at-risk drivers; in terms of the latter, increased congestion at the curb side due to proliferating pick-ups and deliveries increases potential for crashes among vehicles as well as other road users. In addition, as software and connectivity play a much bigger and more critical role for the safe operation of CAVs, these vehicles may be at greater risk for cyber-attacks.

Safety messages provided by V2V and V2I technologies should enable drivers or automated vehicle systems to take actions that could reduce the severity of traffic crashes or avoid them. Such messages simply warn the driver (in the case of non-highly automated CVs) when there is high risk for collision but do not automatically apply the brakes. Their effectiveness depends upon drivers having the applications in their vehicles, turning them on, and paying attention to the warnings. A study of V2V devices installed as part of the Connected Vehicle Safety Pilot Model Deployment in Michigan found that the devices were technically able to transmit and receive messages, and safety applications enabled by these devices were effective in mitigating potential crashes (Harding et al. 2014[27]). But it also noted that various aspects still

[24]Chan, E., P. Gilhead, P. Jelinek, P. Krejci, & Robinson, T (2012). Cooperative control of SARTRE automated platoon vehicles. 19th ITS World Congress Proceedings
[25]Beede, D., Powers, R., & Ingram, C. (2017). The Employment Impact of Autonomous Vehicles. U.S. Department of Commerce, Economics and Statistics Administration, Office of the Chief Economist. Retrieved May 2018 from http://www.esa.doc.gov/sites/default/files/Employment%20Impact%20Autonomous%20Vehicles_0.pdf.
[26]TRB, 2018 Nick Reeds, et al.
[27]Harding, G., R., Yoon, J., Fikentscher, C., Doyle, D., Sade, M., Lukuc, J., Simons, J., & Wang. J. (2014). Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application. Report DOT HS 812 014. Retrieved

needed further investigation including: the impact of spectrum sharing, ability to mitigate V2V communication congestion, incorporation of GPS positioning to improve relative positioning, remedies to address false positive warnings, and driver-vehicle interface performance.

The safety and economic benefits of driver assistance technologies have driven their adoption in regulation in the European Union with lane departure warning and automatic emergency braking systems made mandatory from 2014 (European Commission 2009). In the United States, there has been significant trialling and development of platooning technology to improve vehicle fuel efficiency (e.g., Peloton, see Simpson 2018[28]). If the implementation of higher levels of vehicle automation can further reduce the incidence of collisions, these benefits can be extended still further with greater vehicle uptime and reduced insurance and repair costs.

Over 90% of all traffic accidents are caused by human error. Platooning holds the promise to overcome these human-induced accidents.

4.3.2 **Traffic efficiency**

Travel behaviour impacts: congestion impacts

As CAVs will gradually increase their presence in the mix of regular vehicles it can cause the change of users' behaviour. Accessibility of shared mobility services in cities is expected to decrease the overall number of vehicles on streets and yet reducing congestion. Conversely, the availability of automated and autonomous mobility services enables access to these services of those customers who previously were not able to drive themselves: vulnerable users such as elderly or people with disabilities. Better access to these types of services is expected to change people travel behaviour especially in cities but also (however with less impact) long distance travel made on highways. The availability of shared mobility services utilising CAVs should contribute to less congestion in general. According to Millonig and Shaheen[29] (TRB 2018) the ease of use and limited cost of CAV services makes them very popular, and demand for traditional transport modes has been dramatically decreasing, prompting severe cuts in public transport and the reduced use of non-motorized modes. Despite the resulting increase in congestion, just about everyone is using CAVs, even for short trips, while mobility outside the urban core is almost entirely serviced by CAVs. Travel cost savings also drive an increase in the shared use of CAVs, despite some resistance arising from security concerns. How increases in road travel will affect traffic congestion remains highly uncertain and is dependent on the degree in which automated vehicles will be capable of "coordinating" themselves for a better use of the roads. As a consequence, road trips may slow down, and more time is spent in cars. This increases the opportunity cost of time of car travel.

Regarding automated freight and truck traffic, deployment of truck platooning has proven more efficient operations: reductions on CO_2 and less congestion primarily caused by single commercial vehicles traveling also in left lanes (platoons in dedicated lanes). Fuel consumption reduces in trucks platoons, and it is possible to avoid hours-of-service restrictions, leading to savings to truck companies. Driver tasks would change, possibly leading to losing driver jobs in the long-term. The energy impact of specific fuel savings will possibly be offset by the

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May 2018 from http://www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf

[28]Simpson, B. (2018). Peloton predicts commercial launch of truck platooning service this year. Transport Topics. Retrieved May 2018 from http://www.ttnews.com/articles/pelotonpromises- commercial-platooning-2018.
[29]Millonig, A., & Shaheen, S. (2018). Socioeconomic Impacts of Automated and Connected Vehicles, Connected and Automated Vehicles and Travel Behavior Impacts, Washington, DC: The National Academies Press. https://doi.org/10.17226/25359

additional fuel consumption linked to an increase in road traffic kilometres (EC 2018)[30].

Revenues from road transport commercial operations could increase as fuel consumption and travel time decreases with truck platooning. The number of truck drivers needed could also decrease, although wages could increase due to a more technical role, e.g. monitoring the CAV and if driver time restrictions no longer apply. Whilst the potential loss of truck driver jobs is considered a negative result of automated driving, the reality is that there is a significant shortage of truck drivers, an old workforce and too few new entrants to the sector. In the UK, there is a shortage of 59,000 jobs, 60% of the drivers are over the age of 44 and only 19% are under the age of 35[31]. It was also reported that too few young people are entering the sector, as there is a lack of understanding of the industry, poor sector image, working hours and lack of quality driver facilities. Automated driving potentially solves part of the skills shortage, whilst potentially making the sector more attractive. Possible modal shifts towards road transport (e.g. from rail or sea) could appear because of the more efficient road operation, although the likelihood of this possible change is judged to be low as already today most freight is moved by trucks and national policies are actually suggesting that the change should go in the other direction.

4.3.3 Customer service

Customer service: Security by design, standards, and legislation

Cybersecurity, in the context of vehicle systems, refers to security protections for systems in the vehicle that actively communicate with other systems or other vehicles (Bryans et al. 2017[32]). While cybersecurity issues are a challenge for CV, security becomes a bigger concern with Level 4 and Level 5 automated vehicles, in which software and connectivity play a much bigger and more critical role for the safe driving of vehicles. Unlike traditional vehicles, automated vehicles may be vulnerable to cyber-attacks that can spread from vehicle to vehicle, which may constitute a new type of safety threat. In the case of a cyber-attack the safety of passengers in an automated vehicle and other road users could be at risk. In a case of hacking and stopping a fleet of automated vehicles, the transportation system could be halted with potential safety reduction, even though no real case of malicious car hacking so far been reported. Miller and Valasek (2015[33]) exposed the security vulnerabilities in automobiles by unmaliciously hacking into cars remotely, controlling the cars' various controls from the radio volume to the brakes. All entry points into the vehicle, such as Wi-Fi, the OBD-II port, and other points of potential access to vehicle electronics, could be potentially vulnerable to real-time intrusion (hacking) that could affect the mechanical operation of the vehicle. Many vehicles communicating to/with each other is essentially an ad hoc, self-forming network of devices with no server-side security (McCormick 2017). Cybersecurity, therefore, is a new factor that shapes the existing crash externality.

Issues connected to open data, data sharing, and data ownership that are all highly associated with CAVs have the potential to increase privacy risk, which is the likelihood of a privacy problem occurring and the potential magnitude of harm arising from it. Linking the degree to which data access is controlled (i.e., greatest ease of use of data to greatest privacy protection) is important for mitigating negative societal impacts from misuse or mistreatment of personal information.

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[30]An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe, EC, 2018.
[31]https://fta.co.uk/media/press-releases/2019/october-2019/hgv-driver-shortage-climbs-to-59-000
[32]Bryans, J. (2017). The Internet of Automotive Things: vulnerabilities, risks and policy implications. https://doi.org/10.1080/23738871.2017.1360926
[33]Miller, C., & Valasek, C. (2015). Remote Exploitation of an Unaltered Passenger Vehicle. Retrieved May 2018 from http://illmatics.com/Remote%20Car%20Hacking.pdf

Cyber security

Cyber security is of interest from the CAV operations perspective not only due to the technology-focussed aspects of vehicles and infrastructure, but also from societal point of view. In order to ensure a safe and secure CAM ecosystem, there is a necessity to regulate and set standards of best practice and guidance, as well as formal standards. Cyber security is seen as a fundamental part of public acceptance, which is vital for the uptake of CAM through the delivery of desirable services. Technology areas such as digital infrastructure, connectivity and automated driving systems, rely heavily on cyber security. Testing and development infrastructure in these areas is needed to enable dedicated research for best practice of cyber security (Zenzic Roadmap, 2019). The interactions between vehicles, infrastructure and third-party services across rapidly evolving applications and highly diverse uncontrolled supply chains could also make managing risk across this emerging critical national infrastructure very complex. A main challenge is to face the cybersecurity risk of CV, which can compromise the privacy of users' data, as well as their safety. In this context, the reputation of automated vehicles and their manufacturers/suppliers is at stake, should a cybersecurity attack become real, affecting users' trust on automated vehicle technologies.

4.3.4 Maintenance and construction

Construction and maintenance equipment

There are numerous examples of developments of autonomous or semi-autonomous machinery in the construction industry [34] [35] [36], ranging from machine assistance to some examples of full autonomy.

Trimble[37] report, that there are over 100,000 earth moving (dozer) vehicles fitted with machine control worldwide. Whilst semi-autonomous machines still rely on a skilled operator, technology can enable experienced operators to run 41% faster and 75% more accurately, whilst new operators will run 28% faster and 100% more accurately. Increased automation of steering and other controls is likely to improve productivity further.

There are emerging examples of connected and automated plant and 'machine assisted' plant being deployed in the highways sector. Some are autonomous versions of existing machines, some have been developed by robotics companies to fulfil a specific need, whilst others have come from other sectors.

In terms of tasks being undertaken autonomously, it is the simple repetitive tasks that will initially be replaced. A research article by Volvo construction machinery[38] states that there are some tasks, such as a skilled excavator operator, precisely and accurately controlling the bucket that are beyond the capability of current machines, however the same skilled operator is currently required to also undertake simple and repetitive tasks that a machine could ceaselessly undertake.

Volvo[39] are engaging in range of research, development and demonstration projects around autonomous vehicles, including a self-driving truck in an underground mine in northern Sweden, an autonomous refuse trucks, autonomous buses and an autonomous solution transporting limestone from an open pit mine to a nearby port.

[34] https://cacm.acm.org/news/224172-autonomous-construction-vehicles-are-building-the-future/fulltext
[35] https://future-markets-magazine.com/en/markets-technology-en/autonomous-construction-machines/
[36] https://www.equipmentworld.com/tag/autonomous-construction-equipment/
[37] https://www.conexpoconagg.com/news/how-autonomous-construction-equipment-will-revolut/
[38] https://www.volvoce.com/global/en/news-and-events/news-and-stories/2019/the-rise-of-the-robots-the-experts-view/
[39] https://www.volvogroup.com/en-en/news/2018/jun/focus-on-automation.html

Caterpillar[40] meanwhile, have been deploying automation in the mining sector for several years, with innovations raging from operator assist technologies to control specific machine functions, remote control systems to move operators out of cabs and finally, fully autonomous trucks.

One area with a specific focus is in compactors, as the correct level of compaction, with an equal number of passes over each section has a strong influence on the subsequent road quality and longevity.

BOMAG[41] has undertaken a research study to develop a fully autonomous tandem roller, name 'ROBOMAG' containing GPS, Lidar and advanced position sensors, enabling it to be used fully autonomously in defined work areas or using remote control. BOMAG's 'Asphalt Manager' software monitors compaction power and ensures that compaction performance is accurately documented.

Machine assist

Whilst some technologies will replace the need for human involvement, there are areas where machines can be used to assist the workers to increase productivity and performance.

Volvo have created a semi-autonomous excavator[42] which achieve perfect grading, particularly useful for novice operators. The Volvo Active Control is a machine control system, operated through an in-cab 'Volvo Co-Pilot' tablet. Once the job parameters are entered into the system, the excavator automatically adjusts the boom and bucket movements to make precise cuts, follow the desired shape and deliver exactly the right angle of grade.

Volvo claim that grading times are reduced by 45% compared to conventional grading, with zero rework as the system achieves perfect results first time. An additional benefit is that a second person is not required to take depth/grade checks which also improves safety.

The system also ensures that hazards are avoided through a depth limit, avoiding known underground utilities, a height limit with a pre-set safe elevation, avoiding powerlines for example, and finally, a swing fence prevents the machine hitting obstacles to its side. Hitachi Construction Machinery[43] have developed a hydraulic excavator with digging operation assist. This enables the operator to set a pre-defined plane using on-board monitoring screens preventing the bucket for going beyond the plane, which is usually horizontal, but can be set at any angle to the horizontal. This feature is particularly useful for activities such as underwater or long ditch construction, where the operator cannot easily see a guideline for digging reference. Additionally, they are generally increasing the use of ICT in construction generally, using unmanned aerial vehicles for inspection, 3D point clouds to accurately calculate soil volumes and a reduction in labour for setting out and surveying.

4.3.5 Cooperation services / C-ITS

It is expected that (CVs) will significantly improve mobility and, as an enhancement to automated vehicles (AVs), CV technologies will also enable direct interaction of equipped vehicles with infrastructure and other vehicles to maximize understanding of the environment while minimizing both crash risk and energy consumption. In terms of opportunities for road operators, among which improvements include:

[40] https://www.cat.com/en_US/articles/customer-stories/built-for-it/thefutureisnow-driverless.html
[41] https://www.bomag.com/ww-en/press/news-videos/future-study-fully-autonomous-tandem-roller/

[42] https://www.volvoce.com/global/en/news-and-events/press-releases/2019/top-grades-at-top-speed-with-volvo-active-control/
[43] https://www.hitachicm.com/global/company/company-profile/research/development-of-hydraulic-excavator-with-digging-operation-assisting-system-and-multi-monitoring-display/

- Road operation: traffic monitoring, event management, traffic management and Road Network Operations in general.
- Traffic information: thanks to C-ITS, the road operator can also get the possibility to improve the way he manages traffic information, such as information on RW, road conditions, weather conditions, diversions and so forth.
- Infrastructure planning: the road operator will be able to improve the way he deals with infrastructure planning thanks to quantitative and qualitative data he can collect through C-ITS.
- Road safety: safety is one of the most important focus area where C-ITS is expected to bring improvements, especially in the following safety areas: collision reduction, protection of vulnerable road users, traffic condition warning and safety for road workers in the field.
- Environmental impacts of vehicles through reduced congestion thanks to services such as Green Light Optimal Speed Advisory (GLOSA), Traffic monitoring using Probe vehicle data and Smart Routing.

However, before deploying C-ITS services on his road network, the road operator needs to take some important decisions and the challenges are huge:

- choice and prioritization of the services to deploy
- the technology associated to these services
- make some changes in its organization and
- how to ensure the right data protection

Thus, before deploying, the road operator needs to understand the challenges and benefits of C-ITS deployment. To do so, significant prototyping and testing will be required. Therefore, in order to facilitate the understanding of CITS deployment, it is better to proceed to a testing phase before deployment, using an open road-testing facility.

4.4 Benefits of using test sites for road-operators

It is expected that CAVs can offer major benefits, such as improved safety and increased throughput on the road network. Fully automated or driverless vehicles have the potential to make fundamental changes to how we consider mobility and the design of our urban conurbations themselves.

Benefits of using a testing facility on open road

Before deploying equipment at a large scale, a road operator needs to understand the challenges and benefits of CAV deployment and therefore significant prototyping and testing are required. To facilitate the understanding of CAV deployment, testing facilities are environment that enable the development and assessment of early stage CAV applications. As an example, on a testing facility on open road, several services can be implemented and their impact on road safety, other users' behaviour, traffic congestion, fuel consumption and CO2 emission, driver comfort and fatigue can be assessed. Examples of services that can be deployed on a testing facility on open road are: Road hazard warning, Traffic jam ahead warning, In vehicle speed limit and in-vehicle signage.

Benefits of using a testing facility on a closed and controlled environment

Testing facilities on a closed and controlled environment focuses more on technology validation and safety, and therefore enable:

- Researchers, entrepreneurs, small and medium enterprises and multinationals to develop, demonstrate, and commercialize new technologies for automated vehicles.
  Examples of focus areas of research in a testing facility on a closed and controlled environment: Object detection, tracking and fusion, detection of cybersecurity threats, digital infrastructure including HD Mapping.
- NRA to develop new technologies solutions or new operation solutions or strategies before deploying them in real conditions

  Examples of use of a testing facility on a closed and controlled environment from the road operator:

  - Autonomous Shuttles: pre deployment of use cases, acceptability, human factors, infrastructure design and adaptation Solutions
  - Intelligent parking-guidance system
  - Interactions between CAV and pedestrians
  - Testing of pavement marking for CAVs

4.4.1 Examples

Example 1: Testing a use case for driverless shuttle before deployment on public road

For a road operator who would like to deploy a use case using a driverless shuttle, safe operation is his highest priority. Therefore, before launching operation on the public shuttle route, proceeding to some preliminary tests inside a Test Facility is highly recommended. This is a key element to help define the operational design domain (ODD), of the shuttles, which is helpful to finalize the final route on public road. The ODD defines the specific location and conditions under which the shuttle operates. Some of the ODD parameters are provided by the OEM. The testing phase in the enclosed environment, which will allow him to test critical conditions repeatedly and safely before the deployment on public road.

Example 2: Testing of pavement marking for CAVs

Pavement markings is an important enabler of the development and deployment of CAV. A testing facility on a closed and controlled environment can help test and evaluate pavement markings for CAV operational readiness under various pavement, lighting, and weather conditions.

Example 3: Evaluation of CAVs

The fast-paced development of new CAVs demands thorough evaluation before being allowed on public roads. A closed environment is may serve as a feasible starting point for early stage development, whilst an open environment could provide test prerequisites for evaluation of more mature technology.

Example 4: Evaluation of communication equipment

Some test sites allow testing of various communication devices and can simulate black spots, tunnels and high buildings by blocking or partially blocking signals. Not only might this not be possible to achieve in such a controlled and repeatable way in a highway environment, but it enables potentially dangerous activities to be undertaken in a safe environment.

4.5 Case-studies

Four cases were selected for in-depth analysis to provide a concrete overview of activities at a specific site or in a specific project addressing aspects that align with the work of NRAs, these were:

- Highways England: Construction and maintenance vehicles, work zone safety
- TRANSPOLIS test site: cyber security and data case study and self-driving vehicle cyber security testing capabilities
- ENSEMBLE project: Truck platooning
- ZENZIC: CAVs cyber security testing capabilities

4.5.1 Construction and maintenance vehicles for work zone safety – white lining case study

<table>
<tr><td>Title:</td><td colspan="2">White line pre-marking robot</td><td>Location:</td><td>UK</td></tr>
<tr><td colspan="5">Business Area</td></tr>
<tr><td>☒ Road safety</td><td>☐Traffic efficiency</td><td>☐ Customer Service</td><td colspan="2">☒ Maint/Construction</td></tr>
<tr><td colspan="5">Use Cases</td></tr>
<tr><td>☐ Highway Chauffeur</td><td>☐ Shuttle bus</td><td>☐ Freight Vehicles platooning</td><td>☒ Driverless maintenance and road works vehicles</td><td>☐ Other:</td></tr>
<tr><td colspan="5">Problem addressed</td></tr>
<tr><td colspan="5">Highways maintenance operatives have one of the most hazardous occupations in the UK. Working practices, based on traditional technologies are very labour intensive and have only ever undergone slight incremental improvements in respect of safety, efficiency and performance.

Traditional pre-marking methods involved engineers calculating location of the new road markings, walking the route (often several kilometres) and marking out using aerosol paint or chalk. This process has numerous issues:

• Safety
- Vulnerable operatives or engineers on the carriageway.
- People / plant interface risks from site traffic / incursions from unauthorised vehicles.
- Potential back injuries from bending over to spray for many hours.
- Using a potentially hazardous substance in a windy environment.
• Efficiency
- Numerous calculations and measurements.
- Slow speed at which operative can walk and complete task.
- Fatigue slowing process down further towards end of shift.
- Performance
- Susceptible to human error, especially as fatigue sets in.
- Low accuracy.</td></tr>
<tr><td colspan="5">Solution developed</td></tr>
<tr><td colspan="5">WJ collaborated with a European partner to develop a robotic system that could carry out</td></tr>
</table>

the process autonomously. The Robotic PreMarker uses connected automated driving (CAD) software to draw where road markings need to be placed using global co-ordinates via GNSS. Once inputted the robot is then able to autonomously mark these points on the carriageway. When pre-marking, highway engineers normally work to an average tolerance of 25mm. The WJ Robotic PreMarker was accurate to within 5mm. Not only had the robot dramatically reduced the time taken to complete the task, it was far more accurate than previous methods.

This speed up the time taken by roadworks and also provides the following benefits:

- Improved People, Plant Interface risk management - The new robotic process removes vulnerable operatives and client's engineers off the carriageway and out of harm's way.
- 100% reduced back injury as the process eliminated the engineers constant bending.
- 75% general reduction in exposure on site due to increased process speed.
- Enhanced accuracy and efficiency so reduced rework and new process readily accepted.
- Zero RIDDOR or Accidents during pre-marking with Robot during 2018/2019.
- Positive feedback from site - Client and Employee wellbeing.

An added benefit provided by the WJ Robotic PreMarker is that much of the work can be done from the safety of the office. All drawings are done, either on the tablet or the CAD software and then only need to be saved on a USB, greatly reducing time spent on site.

Figure 5. Illustration of new automated process for maintenance.

Economic Benefits

The technology has been used on several sites and has greatly reduced the time needed to complete different tasks.

M6 – Balfour Beatty Vinci JV - 8km Surfacing works 1m Centres WJ Robotic PreMarker = 3.5 Hours Engineer = 80 Hours Saving = 76.5 Hours	M1 – Costain & Galliford Try JV - 3km Outside Lane Edge WJ Robotic PreMarker = 2 Hours Engineer = 6 - 8 Hours Saving = 3 – 6 Hours
M60 – Manchester Smart Motorway - Slip Road and Tiger Tail WJ Robotic PreMarker = 0.75 Hours Engineer = 2 Hours Saving = 1.25 Hours	M4 – Colas/Balfour Beatty - 5km Hard Shoulder Both Carriageways WJ Robotic PreMarker = 5 hours Engineer = 32 hours Saving = 27 hours

It is relatively difficult to calculate the cost savings as this is offered as a service to clients

whose engineers would otherwise have to complete the task. The standard shift is 10 hours and it has been estimated that the direct cost per engineer would be around £200-£250 a shift, i.e. £20 - £25 per hour. Based on the examples provided, it appears that the greatest savings are on the longer sections where it would take engineers several shifts to complete the work. Taking the greatest saving of 76.5 hours, the direct savings would be between £,1,530 and £1,912.50, however this does not take into account the indirect benefits from completing the work early in opening lanes up more quickly, thereby improving traffic efficiency and customer services. It also does take account of the fact that rather than spending time on a monotonous task, engineers can be used on more value-added activities
Social benefits
From a social standpoint, at the most basic of levels, there is significant value in robots replacing humans for monotonous tasks, freeing them to undertake tasks that require advanced cognitive functions. At a product specific level, the societal benefits are from a reduction in exposure to risk to the highway workers and reduced bending, the completion works more quickly and a reduction in inconvenience to customers. By reducing monotonous tasks, there is the potential to create new, skilled jobs which will be of benefit to society. The manufacturers hope that new career opportunities in turn make the industry more attractive once people perceive it as a more technologically minded sector. This potentially will help ease a chronic skills shortage, by making the industry much more attractive to younger people looking for exciting career opportunities. In turn, a more skilled, research focussed workforce, should produce more innovation.
Impact
A relatively simple product has had a significant impact on an area of highways maintenance, saving money, time and improving safety. It has also shown how innovation and robotization can bring positive benefits to the sector and should encourage additional development in the area.
Further development
The manufacturers see this as a catalyst for new thinking and innovation and see potential for new developments for other tasks. Such has been the positive reaction to the PreMarker, that both the WJ Group and the wider highways industry that already we are increasing investment in robotics and other companies are readying to place orders. The Danish robotics company (Tiny Mobile Robots), who worked with WJ Group on this project offer two variations of the robot for site surveying and line marking of sports pitches. For all three robots, they have developed an android tablet app, to plot coordinates on a map, to double check on site that the drawings match and to make the system easier and more intuitive to use.
Lessons for NRAs
Innovations such as this, the autonomous impact protection vehicle and automated cone laying trials are reducing the exposure of workers to hazards and increasing efficiency. NRAs could promote the development of such innovations through innovation competitions. A further key area of support would be to help companies bridge the innovation ‘valley of death’ by becoming early adopters.

4.5.2 TRANSPOLIS test site examples of use cases

The emergence of the completely autonomous and connected vehicle requires research challenges to be addressed. Among them, let us quote as examples the themes that TRANSPOLIS test site will allow to treat in a systemic and representative way the reality:

- The development of perception systems requires increasingly sophisticated sensors that must be tested, characterized and validated under every conceivable condition,
- Artificial intelligence using sensor data must be effective over an almost infinite number of road scenarios,
- The gradual increase in the level of delegation of control raises questions of human-machine collaboration that must absolutely be addressed by experts in the field of human factors.

Below is a description of the ecosystem and potential users

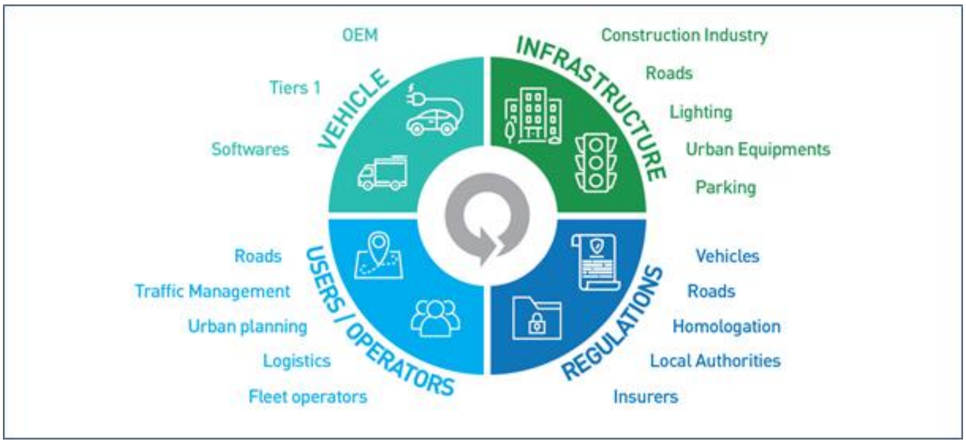

Figure 6. Description of the TRANSPOLIS ecosystem and potential users.

TRANSPOLIS focuses on the deployment and use new technologies and their impacts on several areas, among which operation, traffic management, safety, multimodality, accessibility and so forth. In addition, C-ITS is expected to significantly improve road safety, traffic efficiency and comfort of driving, by supporting the driver. C-ITS and automation are complementary; they support and complete each other and will merge completely over time. Indeed, with C-ITS a self-driving or a normal vehicle will be informed that there are vehicles around it, even if not immediately visible. Another example is the Truck platooning where connectivity and automation must all come together to make it work. TRANSPOLIS aims also at focusing on these areas of research.

Use of intelligent transport systems

The first main objective of this platform is to be able to immerse end-users of the technologies in an environment closest to reality by offering an urban universe on a scale 1.

Service, use and sharing of space

An important axis of TRANSPOLIS activity is to address questions of use of the urban roads such as:

- Multi-modality and interaction of mobility in the face of heterogeneous urban services.

- Urban logistics: development of delivery areas and tests, silent unloading, system approach with shops for night deliveries without merchants' presence, with automatic locks.
- Accessibility of buses and tram to wheelchairs: tests in augmented reality.
- Comfort of traveling by bike in the city: evaluation in real urban environment.

Connected and autonomous vehicles and ADAS

A second axis of TRANSPOLIS Activity is to address questions related to the behaviour of the users of the automated vehicle such as:

- Understanding driver behaviours related to ADAS.
- Analysis of situations of take-over or delegation of driving on more or less automated vehicles (from the current ADAS to the autonomous vehicle).
- Information coming from the infrastructure: Analysis of the understanding by the users. The interaction will involve information related to comfort, security, and traffic.

Urban Data Management

Thanks to the comprehensive optical fibre coverage, TRANSPOLIS will allow a very important collection of data for decision making, City dashboards, score cards and monitoring of smart cities. As illustrative examples, we can mention:

- Big data: collection and real time processing of large amounts of data for urban mobility, security for mobility pattern and system management.
- Innovative Data Fusion of heterogeneous sensors for KPIs extraction (vehicle trajectories, macroscopic traffic characteristics,).
- Validated data repository: quality results database (simulation - experimentation).

Development of intelligent transport systems

This platform has a second main objective, which is to test the development of new technologies for intelligent transportation Systems (ITS).

Innovative Traffic Management

One of the major challenges of traffic engineering is to be able to test innovative traffic management solutions through improvements and new management and regulation algorithms. This platform will make it possible to address research questions requiring a strong experimental component of the type:

- Traffic Control with critical safety applications in a controlled situation and testing of new traffic control strategies.
- Insertion of autonomous vehicles in overloaded roundabouts to test and improve algorithms.
- Connected and intelligent intersections (e.g. GLOSA system).
- Innovative management of CAVs.

The coupling of traffic simulation and field experimentation is a major asset for linking this research to the TRANPOLIS platform.

Connected and automated vehicles

Regarding CAVs, one major issue is to be able test critical situations that could disrupt CAV system. This platform will make it possible to address research questions such as:

- Perception: poor perception situation (black, glare disturbances) for ADAS and coupling it with immersive simulators.
- V2V and V2I: Red light violation warning, Park and Ride information, Emergency Vehicle Approaching, Road Hazard Warning (adverse weather), Road Works Warnings, Dedicated and Dynamic Signage.
- Secondary safety: Prediction of postures to be retained for passengers in autonomous vehicles to guarantee good safety against potential hazards and accidents.
- Precise geolocation for the autonomous vehicle: multi-vehicle multi-sensor systems, fixed ground camera systems and poorly equipped vehicles to be qualified in the hidden areas of TRANSPOLIS and virtually.
- Definition of protocols, methods, tools and metrics for the evaluation, validation and pre-certification of automated and connected mobility systems.

Urban Data Management

Thanks to the comprehensive optical fibre coverage, TRANSPOLIS test site will allow a very important collection of data for decision making, City dashboards, score cards and monitoring of smart cities. As illustrative examples, we can mention:

- Big data: collection and real time processing of large amounts of data for urban mobility, security for mobility pattern and system management.
- Innovative Data Fusion of heterogeneous sensors for KPIs extraction (vehicle trajectories, macroscopic traffic characteristics,).
- Validated data repository: quality results database (simulation - experimentation).

Special focus on cybersecurity related to a connected-vehicle environment

Although CAV can potentially bring some important benefits to our lives and society, issues such as cyber security threats, which may reveal drivers' private information or even pose threat to driver's life, present significant challenges before CAV can be utilized in our society. Thanks to the various technologies of connectivity proposed by TRANSSPOLIS (IoT, ITS G5, 5G, Cellular or Wi-Fi), cybersecurity vulnerabilities in transportation infrastructure can be studied and some recommendations to prevent or mitigate the negative impact from cyberattacks can be defined.

Safety and security

Based on the IFSTTAR's expertise and scientific advance in the human field and its relationship with automated systems, the TRANSPOLIS platform, has a major advantage over other sites for safety and security assessments:

- Safety, security: full-scale intervention test.
- Overtaking manoeuvre of one heavy weight by another, autonomous or not, and response of autonomous vehicles.
- Instrumentation of a bus to measure the real effects on volunteers during emergency situations, such as emergency braking.
- Real emergency response for pedestrians crossing a reserved pathway.
- Protection of vulnerable users (cyclists, motorcyclists) in the city Experimental studies on vehicle dynamics (light vehicles, motorized two-wheelers ...): track tests.

Acceptability studies and human-machine interactions

This platform has been specially designed to address research topics on the behaviour of users in situations of displacement close to reality such as:

- Usability of new developments for road users (pedestrian, cyclists, powered two-wheelers, public transport users, conventional or AV).
- Specification and efficiency of new human-machine interactions (HMI) to inform users of multimodal poles or smart bus stops.
- Acceptability of new autonomous transport systems (shuttles) for users of private vehicles or public transport.
- Specification and efficiency of new HMIs to ensure communication between road users and connected or autonomous vehicles. Accessibility of facilities for all users, including users with disabilities and the elderly.

4.5.3 Truck platooning, the ENSEMBLE project

Context and objectives

The ambition of ENSEMBLE is to realise pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonisation of legal frameworks in the member states.

The main goal of the ENSEMBLE project is to pave the way for the adoption of multi-brand truck platooning in Europe to improve fuel economy, traffic safety and throughput. This will be demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders. During the years, the project goals are:

- Year 1: setting the specifications and developing a reference design with acceptance criteria
- Year 2: implementing this reference design on the OEM own trucks as well as perform impact assessments with several criteria
- Year 3: focus on testing the multi-brand platoons on test tracks and international public roads

Use case definitions

In this project, two platooning levels have been defined:

- Platooning Support Function: here the driver is responsible for the driving task,
- Platooning Autonomous Function: the driver is not responsible anymore; the system performs the complete driving task within the specified operational design domain.

Also, the main properties of the Platooning Support Function are based on Adaptive Cruise Control (ACC). Below are the main high-level use cases of the Platooning Support Function:

- Engaging to platoon
  - Join from behind: either by single vehicle or existing platoon
  - Merge in-between by single vehicle in existing platoon
- Platooning
  - Steady state platooning
  - Follow to stop
  - Emergency braking
  - Platoon gap adaptation:

    - I2V interaction
    - Cut-in
    - System status (e.g. packet loss)
    - Cohesion request
- Disengage platoon
    - Leave
    - Split
    - Leave by steering away

The positive effects of platooning introduction are expected to be seen also in safety. As the human error effect would be reduced, it is expected to have a reduction in accidents. (Janssen et al., 2015[44]). It is uncertain thought, due to the lack of quantitative estimation of the impact of platooning in safety, how important the effect could be. According to the same authors, the introduction of platooning could also lead to an optimization of the road capacity due the reduction in distance between the trucks. In their calculation, the length of road occupied by two platooning trucks could decrease by 46% compared to the current situation without platooning. This would possibly imply longer road's life but also that investments in road projects could be postponed.

4.5.4 Self-driving vehicle cyber security testing capabilities

Title:	**CAVs cyber security**		**Location:**	**UK**
Business Area				
☒ Road safety	☐ Traffic efficiency	☒ Customer Service	☐ Maint/Construction	
Use Cases				
☐ Highway Chauffeur	☐ Shuttle bus	☐ Freight Vehicles platooning	☐ Driverless maintenance and road works vehicles	☒ Other: cybersecurity
Problem addressed				
Technology areas such as digital infrastructure, connectivity and automated driving systems, rely heavily on cyber security. Testing and development infrastructure in these areas is needed to enable dedicated research for best practice of cyber security. Various studies have analysed the possible cybersecurity threats to automated vehicles, as computers possess greater control over the movements of an automated vehicle they are more vulnerable to hacking than conventional vehicles, and the driver is less able to intervene during an attack (Hern, 2016; Lee, 2017[45]). Without sufficient security, V2V and V2I communication channels can be hacked, which can lead to serious accidents (Dominic, Chhawri, Eustice, Ma, & Weimerskirch, 2016; Pinsent Mason, 2016[46]). Injection of fake messages and spoofing of global navigation satellite systems (GNSS) are some of the major threats that automated vehicles will face, as GNSS data can be manipulated to undermine				

[44]Janssen, R., Zwijnenberg, H., Blankers, I., & de Kruijff, J. (2015) Truck platooning driving in the future of transportation, TNO, Netherlands.
[45]Hern, A. (2016). Car hacking is the future – and sooner or later you will be hit. The Guardian. Retrieved from https://www.theguardian.com/technology/2016/aug/28/car-hacking-future-self-driving-security
[46]Dominic, D., Chhawri, S., Eustice, R. M., Ma, D., & Weimerskirch, A. (2016). Risk Assessment for Cooperative Automated Driving. 2nd ACM Workshop on Cyber-Physical Systems Security and Privacy (pp. 47–58). Retrieved from https://pdfs.semanticscholar.org/61cc/e71b6ff9e83d6020f48d197ea5d85affc679.pdf

the automated vehicles' safety critical functions (Bagloee, Tavana, Asadi, & Oliver, 2016[47]). Other threats include the use of sensor manipulation to disorient the automated vehicles systems, bright lights to blind cameras and ultrasound or radar interference to blind an automated vehicle from incoming obstacles (Page & Krayem, 2017[48]). While systems may be installed to detect such malfunctions, these require software updates as well as changing existing standardised security architectures (Bagloee et al., 2016).

Solution developed

The establishment of a vehicle approval process that has cyber security at its core, is pre-dependent on subscribing to common regulations at a global scale, through the UNECE[49] cyber security regulations development.

The EU Cybersecurity strategy was introduced in 2013, followed by the Directive on the security of network and information systems in 2016 (EC, 2017[50]). The latter was the first EU-wide legislation on cybersecurity. Further efforts have been taken by various EU organisations to raise awareness and provide recommendations on how to address cybersecurity issues. In 2016, the EU's independent advisory body on data protection and privacy, the Data Protection Working Party, published its views to raise awareness about developments in the IoT and its associated security issues (Pillath, 2016[51]).

To address a complexity of testing of automated vehicles, including cybersecurity, Testbed UK was established as a global centre for innovation and development of connected and self-driving vehicle technologies and CAM services. These sites comprise a broad range of urban, rural and highway road types, in both controlled and public environments. The facilities also enable the testing of parking and data connectivity across virtual and physical environments, alongside many others.

According to the Zenzic Roadmap (2019[52]) the delivery of a Cyber Security Centre of Excellence in the UK in 2024 will provide a focal point for cross-organisational exchange of research and knowledge. Additionally, it will oversee and facilitate research and development into cyber reliance building upon the Definition of best practice for cyber-secure road-side infrastructure development. The centre of excellence will be a strong voice, providing direction to government on the needs and best practice in placing security as central to safety in the vehicle approvals process from 2026. Without the ability to both develop new techniques for cyber resilient systems and to validate them, CAM services will not be delivered on a large scale and the public will not trust them. Legal frameworks will need to be developed to govern risks as connected and self-driving vehicle services grow to become part of critical national infrastructure.

The cyber security centre of excellence will provide a means to authoritatively identify, quantify and advise on mitigation strategies. Providers of CAM services will be expected to adopt these best practices or potentially be unable to demonstrate that they have taken

[47]Bagloee, S. A., Tavana, M., Asadi, M., & Oliver, T. (2016). Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies. Journal of Modern Transportation, 24(4), 284–303. DOI: 10.1007/s40534-016-0117-3

[48]Page, F. D., & Krayem, N. M. (2017). Are you ready for self-driving vehicles? Intellectual Property & Technology Law Journal, 29(4), 14. [

[49]Proposal for a Recommendation on Cyber Security. Inland Transport Committee: World Forum for Harmonization of Vehicle Regulations. Retrieved 02 July 2019 from https://www.unece.org/fileadmin/DAM/trans/doc/2019/wp29grva/ECE-TRANS-WP29-GRVA-2019-02e.pdf

[50]C. (2017). The directive on security of network and information systems (NIS directive). European Commission. Retrieved from https://ec.europa.eu/digital-single-market/en/network-and-information-security-nis-directive

[51]Pillath, S. (2016). Automated vehicles in the EU. EPRS, European Parliamentary Research Service, Members' Research Service, PE 573.902, 2–12. Retrieved from http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573902/EPRS_BRI(2016)573902_EN

[52]Zenzic Roadmap (2019). Retrieved 06 April 2020 from https://zenzic.io/roadmap/

justifiable steps to mitigate cyber resilience risks, through a Legal framework to deal with the consequences of cyber-attacks. Failure to do this will have a negative impact not only on insurance premiums, but also defences in court if serious incidents do occur.

As highly automated vehicles begin to be deployed, cyber security regulations will be incorporated into vehicle certification regimes and approval. Cyber security and resilience requirements derived from CAM trials will begin to be rolled into the licencing of services, ensuring automated fleets operate safely and effectively.

Another example of how the test sites in partnership with other organisations deal with cyber security is the 5*StarS Consortium including and HORIBA MIRA Thatcham Research and Axillium Research. They received grant funding from the UK's innovation agency to launch the 'Automotive Cyber Security through Assurance' project. The project will address the increased threat from cyber security with the proliferation of connected and autonomous road vehicles.

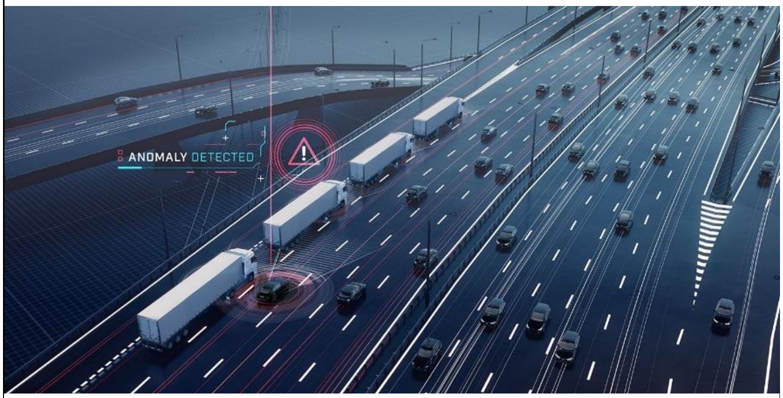

Figure 7. ResiCAV cybersecurity visualisation.

ResiCAV[53] – a ground-breaking programme that looks at how the mobility industry will detect, understand and respond to emerging cybersecurity threats in real-time. The ResiCAV consortium will receive a grant to help CAVs develop real-time responsiveness to cybersecurity threats. The consortium will set out the requirements and specifications for Vehicle Security Operations Centres (VSOCs) that support the monitoring demands of the forthcoming ISO/SAE 21434, plus extend the application of artificial intelligence and data visualisation techniques. Finally, ResiCAV will deliver the requirements for a UK road transport Cybersecurity Centre of Excellence to support the UK's position of meeting the global challenge of automotive cybersecurity head on.

Economic Benefits

Product liability for both CAVs hardware and software will actually constitute a source of new revenues in the future, as well as cyber security risks (e.g. criminal or terrorist hijacking of vehicle controls, identity theft) and infrastructure risks (e.g. malfunction in cloud servers, communication problems), that can amount to $15 billion in new revenues by 2025 (Karp et al., 2017[54]). New insurance revenues will generate at least $81 billion in the US along the period from 2020 and 2025.

Enhancing Testbed UK with digital capabilities will ensure a full test and validation offering. This will see the £1.7 million creation of virtual testing environments completed in 2025, a £20 million centre of excellence for cyber security in 2024, the establishment of a national threat database in 2025 and the adaption of an MOT procedure for cyber security

[53] https://www.horiba-mira.com/media-centre/news/2020/01/23/pioneering-resicav-project-wins-government-cybersecurity-competition/

[54] Karp, L., Kim, R., Liu, C., & Liu, B. (2017). Insuring Autonomous Vehicles. An $81 Billion Opportunity between now and 2025, Accenture and Stevens Institute of Technology, Retrieved from: https://www.accenture.com/t20170530T040532__w__/pl-en/_acnmedia/PDF-53/Accenture-Autonomous_Vehicles.pdf

considerations in 2028 (Zenzic Roadmap, 2019). It is essential the testbeds receive the continual investment they need to test and develop emerging use cases and business models.
Social benefits Cyber security is seen as a fundamental part of public acceptance, which is vital for the uptake of CAM through the delivery of desirable services. In order to ensure a safe and secure CAM ecosystem, there is a necessity to regulate and set standards of best practice and guidance, as well as formal standards. Assess the cybersecurity risks and requirements of CAVs and develop best-practice solutions or a code of conduct assigning responsibilities among various stakeholders, or both.
Lessons for NRAs
Testing of cybersecurity for CAVs should be of significant interest for the NRAs, operating safe and secure infrastructure is one of the key goals for the infrastructure operators. They need to provide for accurate and safe road user services such as incident information and advanced road condition information. Some of these services is currently conveyed to motorist in digital form and more will be available once deployment of CAVs progresses and I2V and V2I becomes a reality on all European roads. NRAs are responsible for providing and maintain of physical and digital infrastructure thus proper approach of managing cybersecurity risks should be a top priority. Technology areas such as digital infrastructure, connectivity and automated driving systems, rely heavily on cyber security. Testing and development infrastructure in these areas is needed to enable dedicated research for best practice of cyber security.

4.6 Identified gaps and conclusions

Currently the reviewed test sites can support the work of NRAs, although there is still room for improvement as the levels of activity at the sites increase. When NRAs involvement in the sites increases, strategical steering of the work conducted at the test site can be tailored to meet their needs. For test sites where the level of involvement is low, one way to get useful information is to encourage an open dialogue. As became evident in the STAPLE project, it can be difficult to gain information from sites for various reasons, such as for example related to funding (what is the benefit for test sites of sharing information?) and ownership of the sites (for whom do they work and which interests are they supporting?). The main conclusion of the work is that test sites have potential to support NRAs when it comes to testing and evaluating new and promising technology with potentially game changing impacts on the overall transport system, but also for specific areas that are directly linked to NRAs work such as construction and maintenance of our road network. Furthermore, to fully support the needs of NRAs, and other stakeholders vis-à-vis test sites, the flexibility of the sites ought to be a key for success. With flexibility, it would be easier for sites to adapt to changes in the needs of stakeholders, but also to new technological developments requiring changed test set-ups. Please note that many test sites do have a high level of flexibility as indicated by a broad project portfolio covering many different areas.

4.7 Summary of impact assessment

In this chapter we have described various impacts including socio-economic aspects, economic aspects, and core areas of NRAs such as safety and maintenance, to mention a few. Furthermore, we gave an in-depth account of carefully selected cases to provide a more concrete view of what test sites can offer NRAs, and examples of beneficial work that can be conducted on open- and closed environment test tracks respectively. From the case studies the potential of test sites and how they can support NRAs in their work with things such as evaluation and testing, standardisation and legislative work, maintenance of our roads and so forth became evident. We also identified several examples of direct impacts of test sites on the responsibilities of NRAs, these include:

- Connected and automated driving will likely have both positive and negative impacts on the economy and society.
- Whilst fully autonomous vehicles may be further away than anticipated at the start of this project, CV offer significant opportunities to increase traffic efficiency.
- Fully autonomous and machine assisted plant offer significant gains in productivity, accuracy and quality. The advent of 5G may introduce the potential of remote operation of plant, further improving operative utilisation, whilst encouraging new entrants to the sector.
- Automated or semi-automated highway platoons will increase fuel efficiency and potentially increase driver utilisation.
- The skills, training, qualifications and continuing professional development offered now, will not be suitable for the future.
- New ways of working and training will be required. What is currently taught in a classroom environment, may quickly become outdated.
- We can speculate on what the impacts may be, but the rapid change of technological advance ensures that nothing is certain.

5 Key findings and next steps

5.1 Key findings

As described in chapter two the chosen STAPLE methodology was adapted due to some matters with the availability of data from test sites which affected the methodology and thereby the analysis. However, we were still able to derive findings that are of value for NRAs and NRA related work. We have shown that:

- Where the level of involvement of NRAs in test sites will significantly influence the research focus and outputs of the sites. Having a strong role, will help steer the results of the sites towards their specific needs. However, they also have the potential to influence the work at test sites where their involvement is weaker, for example through funding of relevant research projects.
- There is highly relevant work conducted at test sites across Europe with clear benefits for NRAs as exemplified in chapter four (evaluation of CAVs, testing specific use cases, testing specific technology for pavement markings).
- Open and closed environments of the test sites are useful for different purposes, although combining them in different stages of testing and evaluation is desirable to gain the positive effects of respective environments.
- NRAs have to adapt their organisations and strategical work in order to be able to fully realise the potential of different test sites, e.g. through strategical roadmaps to make the right investments, contractual agreements on data sharing to access key data et cetera.
- NRAs also have a significant role to play in cooperating with research projects and making data available for industry to test and develop products and technology solutions, as occurs at Midlands Future Mobility and ConVEX.
- Close cooperation between test sites, NRAs and manufacturers should be encouraged to optimise the impact of the research being undertaken, to explore synergies and to potentially co-fund research where there will be shared benefits.
- NRAs, test-sites and wider industry need to understand each other's motivations and business cases. For NRAs, the business case is not always related to a cost-benefit calculation, but on wider objectives such as accident reduction, environmental improvements and opening up opportunities for employment and economic development.
- What has worked in the past regarding training and qualifications, is unlikely to work in the future.

5.2 Next steps

The next stage of the project will summarise the findings of the previous work packages and to produce a comprehensive output that will be valuable to NRAs both now and in the future.

A key objective for this will be to engage with various stakeholders to validate findings and agree content. It had been planned that this would be undertaken at, or shortly after TRA 2020, although the cancelation of this event due to the Corona virus and ongoing travel restrictions might mean that some format of online discussions might be required instead. As this is a fast moving issue, we will respond accordingly, depending on how the situation develops and any lifting of restrictions.

The workshop (in whatever format it takes) will provide the opportunity for specific topics to be discussed, areas to be clarified and presentation format and exact content to be agreed. A key area that will be covered will be on areas where NRA needs are not realised it and potential options to address this. This task will produce the final main deliverable for CEDR and will identify the key findings of the investigation covering the test sites, functions including technical and non-technical aspects. The report will identify how specific test sites address NRA needs as they might develop over the next 20 years and provide recommendations for additions or improvements to address specific NRA requirements (such as for example maintenance and inspection activities), reflected in the in impact and socio-economic impact assessment undertaken in work package 4. Additional information will also be added to the Excel database and test site map produced in work package 2.