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AUTOMATED VEHICLES

CHALLENGES AND OPPORTUNITIES FOR ROAD OPERATORS AND ROAD AUTHORITIES

TASK FORCE B.2 *AUTOMATED VEHICLES: CHALLENGES AND OPPORTUNITIES FOR ROAD OPERATORS AND ROAD AUTHORITIES*

STATEMENTS

The World Road Association (PIARC) is a non-profit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2016– 2019and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org

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International Standard Book Number: 078-2-840606-653-6

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This report has been prepared by the working group Task Force “Automated vehicles: challenges and opportunities for road operators and road authorities” of the Task Force B.2 of the World Road Association (PIARC).

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EXECUTIVE SUMMARY

2021R03EN

AUTOMATED VEHICLES

CHALLENGES AND OPPORTUNITIES FOR ROAD OPERATORS AND ROAD AUTHORITIES

Vehicle Automation – at SAE levels 3, 4 and 5 – is still in a testing phase in most countries. Many tests at level 3 have been performed successfully on open roads without any changes to the road infrastructure and without any observed impacts on congestion. There are various situations which necessitate that a driver takes control of the vehicle – a fall-back solution that is still allowed at level 3, but not at level 4 or 5.

It is likely that some support from the infrastructure will be needed to reach higher levels of automation. In particular, well-maintained lane markings and the provision of landmarks appear to be key features. Automated vehicles cannot, however, rely solely on the physical infrastructure, due to practical limitations; lane markings deteriorate over time, and it is not practical to forecast when they become ineffective for automated operation. Therefore, digital infrastructure, including data provided through high-definition maps and/or through vehicle-to-infrastructure connectivity, is required. Initial insights on this digital infrastructure have been provided in this report.

Regarding the impact on congestion, two factors need to be considered. The first is the operational capacity of physical infrastructure. Some studies indicate that capacity is likely to decrease at low penetration rates and potentially improve only by 2050 or 2055 due to shorter headways. The second is the change in traffic demand. It has been predicted that within the next 20 years, 60% of the the world's population will live in cities. If vehicle use is increased without regulation due to increasing empty automated vehicle trips and changing parking availability, congestion could increase further. The promotion of automated shuttles could help address this risk.

Some studies also show that the impact on road safety should be positive at high penetration rates, as already observed due to greater penetration of Advanced Driver Assistance Systems (ADAS). This assumes that many human factors are considered, such as driver overreliance or loss of driving skills.

The report mentions 11 key challenges to tackle regarding social issues in order to make automation a success.

Finally, in terms of responsibility, a new balance will need to emerge between the responsibility of the road operator and the responsibility of car manufacturers (or even the car itself). This balance could be linked to a certain level of service, but the definition of this level is not yet mature.

CONTENT

LIST OF FIGURES

1 INTRODUCTION

In the last few years, vehicles with different levels of automation have been being tested all over the world. The Society of American Engineers has identified five levels of driving automation (SAE levels):

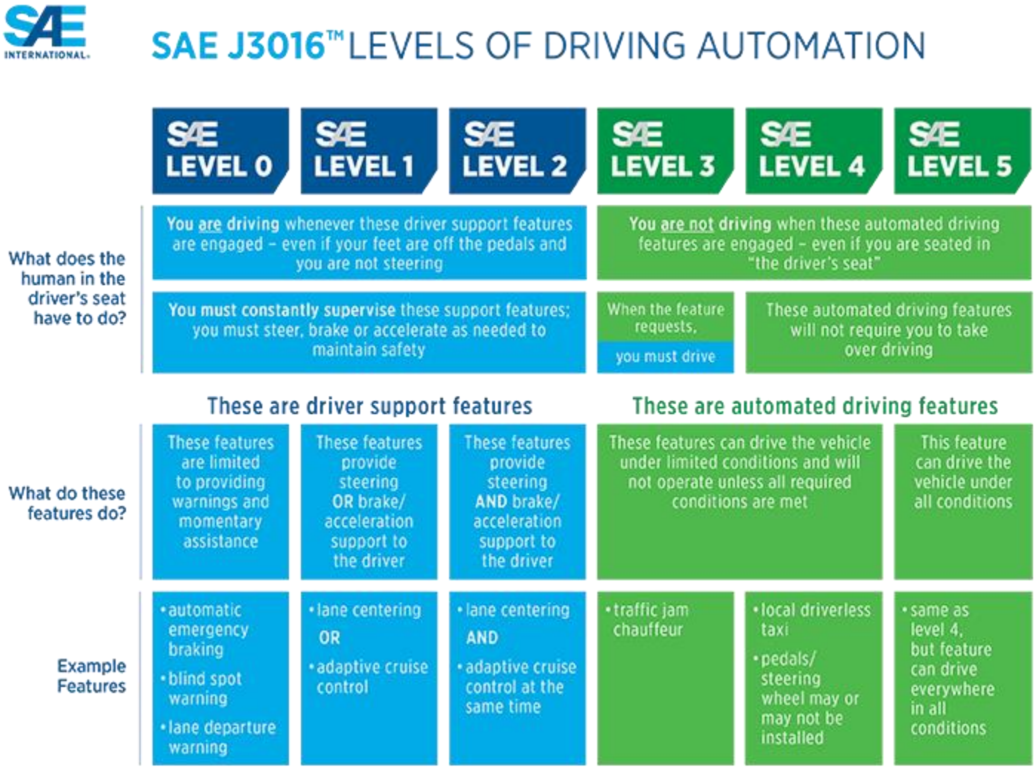

Figure 1: SAE J3016 Levels of Driving Automation [33]

SAE levels 1 and 2 are driver support features, many have been authorized and deployed in a number of countries. Levels 3 to 5 represent automated driving features and are still being tested by car manufacturers with prototypes using different combinations of sensors, Global Navigation Satellite System (GNSS) positioning and sometimes connectivity.

An important aspect to consider is the Operational Design Domains (ODD) for which a feature has been designed to operate within. ODDs are defined in the same SAE standard as "operating conditions under which a given driving automation system or features thereof are specifically designed to function, including but not limited to, environmental, geographical, and time-of-day-restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics." This includes roadway types, speed range, environmental conditions (weather, daytime/night-time, etc.), and prevailing traffic law and regulations.

Road operators and road authorities are keen to understand the impacts of automated vehicles (at different SAE levels) on traffic management, equipment requirements, road safety, maintenance strategies, adaptive control and performance optimization of the network and infrastructure design.

This report provides the current state of understanding for all these questions, based on the experience gathered from testing and experience with vehicle automation all around the world.

The report provides an initial explanation of the methodology used for the gathering and synthesis of the content.

The implications of existing physical infrastructure and its condition on the effectiveness of automation is discussed as well as the impact of automation on the physical infrastructure.

Irrespective of the quality and condition of physical infrastructure, it is evident that automated vehicles will increasingly need to rely on a digital twin of this infrastructure, comprising data transmitted either through connectivity or through digital maps. This is discussed in the chapters concerned with developing this necessary digital infrastructure.

Also discussed is the impact of automation on road network operations and traffic management, with implications for road network planning and road agency capabilities.

The closing chapters tackle legal, economic (responsibility, insurance and financing) and social issues (human factors, including road safety).

2 METHODOLOGY

In producing this report, the Task Force firstly defined the main challenges and opportunities that road network operators and road authorities are likely to face from automated vehicles. An initial workshop meeting defined the main topics for the Task Force to consider – these topics form the chapters of this report.

The report begins with a consideration of the implications and responsibilities for road network operators and authorities on both physical and digital infrastructure. The following aspects of physical infrastructure have been considered: road signs, lane markings, static and dynamic signs and road geometry, and city planning and maintenance; including the potential changes to infrastructure design to facilitate platooning.

Digital infrastructure was identified as a significant area of interest, with consideration given to digital maps, positioning aspects and data. It was recognised that automated vehicles will impact non-technical areas such as responsibilities and insurance as well as social issues. The report concludes with several recommendations including some specific to low- and middle-income countries.

An extensive literature search was undertaken to understand automated vehicle activity – projects, research, trials, and policy development – across the globe. This was followed by workshop sessions which identified a list of existing case studies to be utilised for source material - from Australia, Austria, Canada, China, Czech Republic, France, Italy, Japan, Kenya, Korea, Spain, South Africa, Sweden, and the United Kingdom. A cross fertilisation session was also held with platooning experts from Europe to enrich the report during the PIARC World Congress held in Abu Dhabi. A core team of writers was assigned to each chapter, with reviews by the rest of the Task Force members - to discuss and enrich the content and perspective. This was followed by a consolidation and editing process to finalize the report.

3 PHYSICAL INFRASTRUCTURE

3.1 Road signs

3.1.1 Harmonization of road signs

Road signs are a critical aspect of a safe road network, aligned with the ability of drivers to recognise and understand them. Human drivers are relatively adaptable in their ability recognise and understand signs that look familiar even if not exactly as they had expected. Machines are not necessarily as adaptable. Acknowledging that vehicles are manufactured for global markets, significant international efforts are needed to harmonize traffic signs and road markings to ensure consistent machine recognition and safety [1] performance. Due to economies of scale, the automotive manufacturing industry has limited ability to customize software and sensor system design for each individual jurisdiction. Therefore, industry-government forums are needed at an international level to support traffic sign harmonization. The United Nations Economic Commission for Europe has a working Group on harmonization [2].

There are two major standards for traffic sign harmonization: the US Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways and the Vienna Convention on Road Signs and Signals. There is also the Southern African Development Community Convention and the Central American Integration System Convention. Many countries also use individual systems that combine design principles from both the MUTCD and Vienna Convention. It is also common to have regional differences in signage within countries and even within sub-jurisdictions as well as on private land. Many road authorities have national standards for road signs, but regulation and enforcement are left to local governments. Road authorities that have a national agency responsible for implementing and approving signage have demonstrated significantly more uniform systems [3].

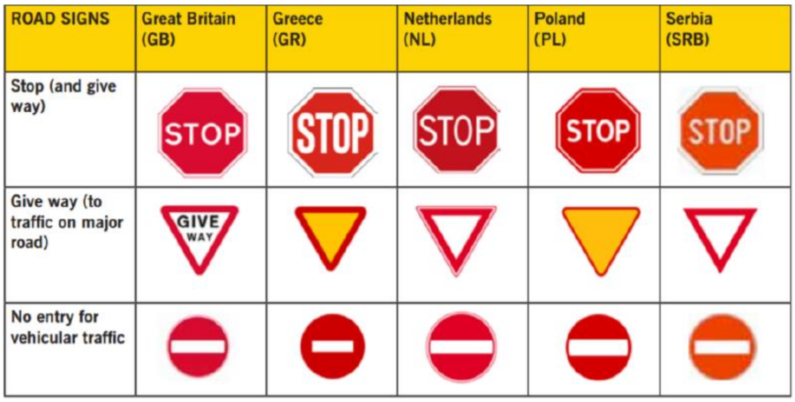

Figure 2 : Examples of variances in Vienna Convention implementations [2]

Some of the key differences and challenges for harmonization include:

- Units - use of the metric system vs. imperial system; some countries do not indicate units on road signs
- Shape – use of diamond, pentagonal or triangular signs for various warning purposes
- Colour – use of orange for temporary signage in MUTCD, use of blue for mandatory information in Vienna Convention vs. supplementary information in MUTCD
- Language – use of text in various languages

Figure 3 : Examples of variances in MUTCD-influenced implementations

The benefits from investing in road sign harmonization include improved machine vision system and algorithm performance as well as limiting barriers to higher levels of ODD implementation and testing. There are also the benefits of reduced need for costly alternatives (digitization), improved human recognition and opportunities to improve compliance through more consistent and reliable in-vehicle alerts.

It is recommended that priority is given to resolving traffic sign issues on expressways/motorways first as this is where the greatest volume of traffic occurs and where higher levels of automated driving are most likely to appear first [3]. Harmonization efforts should also focus on sign shape which is the primary method of recognition as Traffic Sign Recognition (TSR) systems do not distinguish colour well [3].

Harmonization will take time, and even after a consensus has been reached, physically changing signs along every road worldwide will be a significant challenge. Meanwhile, vehicle manufacturers and original equipment manufacturers (OEMs) are introducing different national sign databases in their systems.

3.1.2 Alternative approaches – adding digitization/connectivity

The Task Force noted that some jurisdictions are taking an alternative approach to prepare for higher levels of automation. Rather than waiting for harmonization efforts to advance, jurisdictions may select to digitize all forms of signage by adding infrastructure-to-vehicle (I2V) connectivity or machine-readable code (e.g., Quick Response (QR) code). The HMI (Human Machine Interface) needs to be properly defined. With millions of road signs in each jurisdiction, harmonization should be viewed as a long-term goal. Notwithstanding, there are additional benefits in redundancy from having both harmonization and digitization of road signage.

3.2 Static and Dynamic Signs

As noted in the previous section, there are multiple sign standards around the world for static signs. Most are inspired by either the Vienna convention from 1968 or the US MUTCD first published in 1935.

AV sign recognition systems need to read all these signs, whether they are static, dynamic or electronic signs.

There are four main types of dynamic signs currently in use on roads and highways, built by many manufacturers to a variety of standards and specifications.

Figure 4 : Variable message sign (VMS) source: MTO

Figure 5 : Changeable message sign (CMS)

Figure 6 : Variable Speed Limit sign (VSLS)

Figure 7 : Lane Use Management Sign (LUMS)

3.2.1 Traffic Sign Recognition

Traffic Sign Recognition (TSR) is a technology that enables a vehicle to detect and recognize traffic signs at the roadside e.g. "speed limit" or "children" or "turn ahead". This is an example of an Advanced Driver Assistance System (ADAS). The technology is being developed by a variety of automotive suppliers. Vehicle manufacturers are moving towards enabling speed assistance systems and automated driving systems which use TSR technology; the benefits of successful introduction are likely to be significant for road safety.

TSR uses image processing techniques to detect and recognize traffic signs. The detection methods can be generally divided into colour based, shape-based and learning based methods.

An AV equipped with a TSR system can read and recognize traffic signs. Reliability for the reading and recognition of standard static signs (speed limit, warnings, etc.) by TSR is very high; in Australia and in France pilot projects have demonstrated a recognition rate of these signs of almost 100%. However, TSR systems cannot yet read and recognize way finding signs, non-standard and information/advisory signs.

TSR systems rely on signs to be correctly located and maintained (including cleaning) so that visible light and colour can be captured by cameras.

3.2.2 Traffic Sign Recognition system with dynamic signs

The case studies collated for this report indicate that TSR systems are currently unable to consistently read dynamic signs (roadside signs or gantry mounted sign). Literature and stakeholder interviews indicated that the refresh rate of signs and variability of pixel illumination could vary between brands and designs. Other factors could include the sign size, height and approach angle, as well as level of illumination from the power source.

3.2.3 CMS, VMS, VSLS and LUMS signs

TSR do not generally recognize Variable message signs (VMS) and Changeable Message Sign (CMS) systems as they tend to focus on fixed speed sign recognition. Variable Speed Limit Signs (VSLS) and Lane Use Management Signs (LUMS) also are not recognized by current TSR systems.

3.2.4 Refresh rate

The refresh rate of electronic signs is designed to enable a human eye to see them properly, without flickering. It is necessary to develop a standard that enables a TSR system to do the same. Different standards currently exist, with both the New Zealand Standard and EU guidelines recommend that the frequency of emitted light should be “not less than 90 Hz” while the Australian standard is a significantly higher 2 kHz.

Flickering in the electronic display may be observed by the TSR systems camera causing it difficulties in recognizing the sign. This occurs on some electronic signs and not others. In some cases, segments of the sign may have refresh rates out of sequence with other segments of the sign. Evidence suggests this flickering effect may not be apparent in direct current powered signs, or signs from certain sign manufacturers. This could be improved either by improving either the signs or the cameras. As cameras are getting better year by year the recommended priority would be with camera improvements.

3.2.5 IVS (In Vehicle Signage)

Figure 8:Examples of the effect of LED refresh rates - blackened sections.

A possible solution to the difficulty of detection of fixed or variable signs by TSR systems is to use infrastructure-to-vehicle (V2I) connectivity. With the help of RSUs (Road Side Units) and OBUs (On Board Units) in vehicles, the signs can be identified, read and understood by equipped vehicles. This solution added to TSR systems can improve sign detection, interpretation and response.

3.3 LANE MARKINGS: NOT A ROBUST SYSTEM VS GNSS POSITIONING

3.3.1 Role and challenges of lane markings

Automated vehicle function currently relies on clear, consistent and well-maintained road markings and signs to navigate. Lane markings are one of the main reference elements for automated vehicles in maintaining their position on the road and within lanes. However, current lane markings do not fully meet the needs of automated vehicles. For example, there are various road layouts and situations (road works, tolling plazas…etc.) where there are no lane markings. The regulations for the secondary road network in Austria do not require lane markings to be provided. Weather can cause issues, as some lane markings can be obscured by rain or when the sun is at low angles. To support current levels of automation, the assessment and maintenance of road markings (including testing and assurance of retro-reflectivity) is required.

One of the main challenges for road operators is that it is technically impossible to predict or detect the “failure” of markings (degradation to a point that automation is compromised). It is inevitable that automated vehicles will have to cope damaged or absent markings, which may need supplementary information through digital maps. These digital maps will also be required to be maintained, either manually or through a semi-automated process.

From the information gathered, there is no indication that there is a need for significant change to the design of road markings or road signs, since the current standards are reasonably well defined in most jurisdictions. Concerns raised by OEMs predominantly make mention of the degraded state of road markings and road signs, and not their design.

3.3.2 Lane markings for positioning

It is possible that as vehicles increasingly use other forms of digital infrastructure and mapping to position and navigate, the issue of road markings may become less critical. However, there is a challenge that since many existing advanced driver assistance systems (ADAS) rely on road markings, there may continue to be a reliance on them for some time.

An alternative has been trialled on some automated low-speed shuttles, which needed to consider reduced availability of GNSS signals in mountainous areas and tunnels, and also with reduced functionality of sensors under adverse weather conditions such as fog and snow accumulation etc. Magnetic markers and magnetic-induction lines were installed for vehicles to follow and to identify their location along sections of defined driving routes. Although this approach requires additional investment to provide the dedicated infrastructure, both in the road and vehicles, it enabled vehicles to reliably locate and position themselves along equipped sections. As a result, standards for magnetic markers and magnetic-induction lines are being examined for some automated driving technologies to be realized in the early stages in Japan.

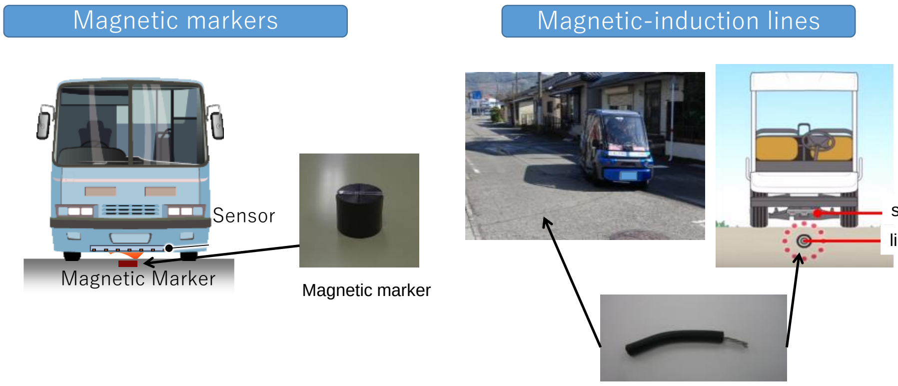

Figure 9: Magnetic markers and magnetic-induction lines (Source: NILIM, MLIT, Japan)

Figure 10: Example of automated low-speed shuttle landmark sign

3.4 NEED FOR LANDMARKS

Road-side units (RSUs) can also be used to provide landmark information. Static or electronic signs with landmark information, such as QR Codes, WIFI or DSRC, could be provided to assist automated vehicles. Several countries such as Germany and China are designing new systems utilising landmarks.

Some AV systems, such as low speed AV shuttles, may have limited localization capabilities and may use sensor data in combination with high-definition maps to determine the exact positioning along a route (i.e. proximity to a landmark). Buildings, utility poles, signs or other distinctive landscape features may be used as landmarks or mounting locations for positioning devices so long as they are unlikely to be obstructed by changing environmental conditions [4].

Figure 11: Landmark positioning as used in Germany

3.5 ROAD GEOMETRY, INFRASTRUCTURE DESIGN

3.5.1 Sign placement

An important factor for TSR systems is the location, proximity, and applicability of signs from where they can be viewed – the TSR system needs to read only those signs that apply to the vehicle. Some field tests have found that TSR systems can read road signs which are not applicable to the road or lane where the AV may be travelling, such as speed limit signs applying to a separate parallel roadway. Attempts should be made to ensure that placement minimises confusion, both for automated and human driven vehicles. Variation in the position of road signs can lead to them being unreadable due to the distance from roadside and angle of the sign face in relation to the traffic direction. Inadequate maintenance that results in signs being dirty, misaligned or having reduced retro-reflectivity can also exacerbate non-ideal positioning.

3.5.2 Pavement marking and dedicated lanes

During the early stages of automated driving development, nominated routes should attempt to avoiding “dynamic” obstacles such as parked vehicles, pedestrians and/or bicycles. To assist automated driving vehicles in operating smoothly and predictably, measures to suppress on-street parking, pedestrian conflicts, and bicycles should be considered. Approaches to clearly define the driving route for automated vehicles (e.g. dedicated pavement marking), and dedicated lanes are under consideration in some jurisdictions.

Figure 12:Pavement marking

3.5.3 Universal design needs to be upgraded

Universal design requires products to be usable by all people without the need for adaptation or stigmatizing solutions, and this should now also include CV and AV. Universal design principles need to be incorporated not only in vehicle design, but also in the design of related infrastructure, such as electric vehicle charging stations. One of the more common technology adoptions for CAVs is the provision of necessary information via road-side units. This requires a stable power supply network and a high-capacity communication network along the all interconnected infrastructure in order to provide sufficient and steady services to CAVs.

There is a possibility of reducing lane widths in some contexts with the potential for CAV to follow an established trajectory with lower lateral oscillation than human driven vehicles. More lanes could be accommodated within the current infrastructure width, increasing the capacity of infrastructure at some locations. This reduction of the width could be applied in highly constrained locations such as bridges and tunnels provided that sufficient safety analysis and consideration of all design vehicles (especially for larger vehicles’ physical widths and swept paths on curves) has been undertaken.

The impacts of some aspects of physical infrastructure design (e.g. road geometry) on vehicle performance could be improved by AV functions. Automation could smoothly recognize horizontal alignments and slopes and adjust performance. Sudden changes in road geometry or width and un-signalized intersections could prove more challenging.

3.5.4 Crossings

At-grade crossings are one of the most crucial physical infrastructure locations that could affect AV and CV design and safe operation. The interaction between pedestrians and AVs will be different to interactions with human drivers. One challenge is the determination of responsibility between AVs and pedestrians. Should, for example pedestrians be expected to have an awareness of the presence of AVs, ensuring they don't proceed in front of a CAV at the wrong moment; or should the AV systems be entirely responsible for detecting pedestrians. Practical limitations of onboard detection systems may result in failure to detect pedestrians under some conditions. Roadside environments can also have objects and furniture that can obscure the view of pedestrians form a vehicle and detection systems may not reliably differentiate a human from an object.

- Uncontrolled or random pedestrian crossing locations: Pedestrians are not a "compliant" or expected part of a system who can be directed and controlled. Pedestrians can be random and chaotic variables for automation to consider which are vulnerable. Pedestrians as potential obstructions on motorways are generally quite rare, although exposure can vary in developing countries, so they still need to be considered for safety. On other road types, the exposure to unexpected crossing behaviour may be greater and the speed environment may be lower but implications for automation functions still need to be considered under a wide range of environmental conditions.
- Zebra crossings: Vehicles are required to stop when pedestrians step onto or are closely approaching a zebra crossing. It may be expected that pedestrians would wait for an approaching vehicle to slow significantly before crossing, however this may not always be the case. Although the priority at a zebra crossing is better defined, automated functions would still need to consider how to navigate such areas as pedestrians may not perceive the difference between automated and non-automated vehicles.
- Signalized crossings: A CAV approaching a signalised crossing needs to be aware of the signal status. It also needs to be recognised that pedestrians may not always wait for the correct signal phase and may cross late or early fail to be clear of the road when the signals change to a vehicle phase. Signal phase setting such as the length of red times and flashing amber display where used could have effects on CAV operation, and some strategies and design changes may be required to improve clarity.

In areas where there is a reasonable expectation of pedestrians crossing the road, whether there is formalised control or not, road operators need to consider the potential limitations of AV detection systems and also the random behaviours that pedestrians might exhibit. This may involve limiting or clearing some areas of visual obstructions that may obscure the lines of sight near a road where AVs may operate. Consideration may also need to be given to better segregation between pedestrians and vehicles, and channelling pedestrians to controlled or clearer crossing locations to improve mutual visibility and priority for both pedestrians and AVs

3.5.5 Emergency stop areas / hard shoulders

The Transport Systems Catapult in the UK (TSC) has assessed the current situation and the change in space of refuge areas and hard shoulders. Traditionally, hard shoulders have been provided along motorways, which provide a continuous strip of hard standing for vehicles to stop in an emergency.

However, in more recent years several sections of motorway have been converted to All Lane Running (ALR) to increase their capacity. The ALR system provides safe harbour areas (referred to as emergency refuge areas), which are spaces at intervals of up to every 2.5 km." Some motorways have been converted to 'Dynamic Hard Shoulder Running', which involves retaining the solid white line to indicate the presence of a hard shoulder and opening the hard shoulder to general traffic or transit buses during busy times via signs and signals.

Figure 13 : Example of continuous hard shoulder (left) and Emergency Refuge Area (right)

3.5.6 Different factors why the AV should stop in a secure area

In full motorway / highway pilot mode, vehicles will be travelling at high speeds with the human driver disengaged from the driving task. It is possible that the driver is not ready to regain control of the vehicle before it reaches the end of its operational envelope. This could be due to several reasons, such as:

- Driver falls asleep, suffers some debilitating incident (e.g. heart attack) or becomes otherwise distracted;
- AV system malfunction or vehicles experience mechanical problems;
- Deterioration of environmental conditions;
- Detection of incidents ahead, such as disabled vehicles in the carriageway, which the AV is unable to negotiate.

In this situation the vehicle will need a safe area to stop and wait for the driver to be ready, or for conditions to improve to the extent where the automated control system is able to proceed.

3.5.7 Safe harbours or hard shoulders?

Studies are needed to determine the most appropriate form of safe harbour for AVs, which could also change over time with changes in automation capabilities and the penetration rates of AVs in the vehicle fleet. The advantage of a continuous hard shoulder is that there is always somewhere to stop at short notice. A disadvantage is that hard shoulders in highspeed environments are not a safe place to stop, especially for extended periods of time. Vehicles travelling in the nearside lane of the motorway can veer into the hard shoulder due to a lack of concentration by human drivers. A highly undesirable scenario would emerge if a driver has fallen asleep and remains asleep for an extended period, placing the vehicle and occupant in a highly exposed and dangerous situation.

Safe harbours may need to be appropriately designed and contain enough space for an appropriate number of vehicles to stop, and regular enough along a route so that AVs can access them when required. Provisions could also be considered to prevent misuse of these areas recognizing that AVs could considerably increase the use of such areas.

The frequency and spacing of these harbours is an area that road operators may need to consider. The distance between harbours will depend on the traffic demand and conditions, and also the type of AVs that could be present on the segment of road. The ODD will need to consider the availability of shoulders or safe harbours and the associated risks, which in turn could influence what level of automation might be achievable over various time horizons.

3.5.8 How sensors work in bad weather conditions

The weather has impacts on road safety which has been clearly demonstrated by historical data. According to the US Department of Transportation [5], over 5.89m vehicle crashes occur each year on average, out of which around 1.24m can be attributed to adverse weather conditions including snow, rain, fog and severe wind. The most common weather-related accidents are due to wet pavement and rainy conditions which account for 76% and 46% of the accidents respectively.

For the purpose of this report, bad weather is generally defined as wet pavement, rain/hail, snow, icy pavement, snow/slushy pavement and fog. For AVs as well as for the human driver, the implications of low friction and the impact on the effectiveness of vehicles sensors are important.

3.5.9 Low friction

In a wet or icy conditions, or on aged pavement, the grip between a vehicle tires and the road can be substantially reduced. Road operators may need to provide pavement friction information and potentially dangerous weather conditions through live digital mapping applications and alerts, although this may be data and time intensive to maintain and keep up to date. AVs needs to be able to assess the road condition and determine how best to manoeuvre during turns, how best to proceed from a stopped position and how to best evaluate the required stopping distance. Losing traction when accelerating or having insufficient distance to safely come to a stop can result in potentially unsafe driving outcomes.

3.5.10 Sensors

AVs typically use a mix of different types of on-board sensor technologies including, LIDAR, RADAR and GNSS to continually update their digital awareness and position and to navigate safely in their surrounding environment. Adverse weather can affect the accuracy and reliability of these sensor technologies. For example, rain, dirt, leaves or snow can obstruct camera lenses, and the necessary image processing can be impaired or prevented without clear imaging. This system is less useful if the lens is not kept clean at all times.

Rainfall and snowfall are interpreted by LIDAR sensors as noise that is superimposed over the background physical environment. Figure 14 demonstrates the distortion of the surrounding environment with a sea of purple objects projected around the vehicle due to snow.

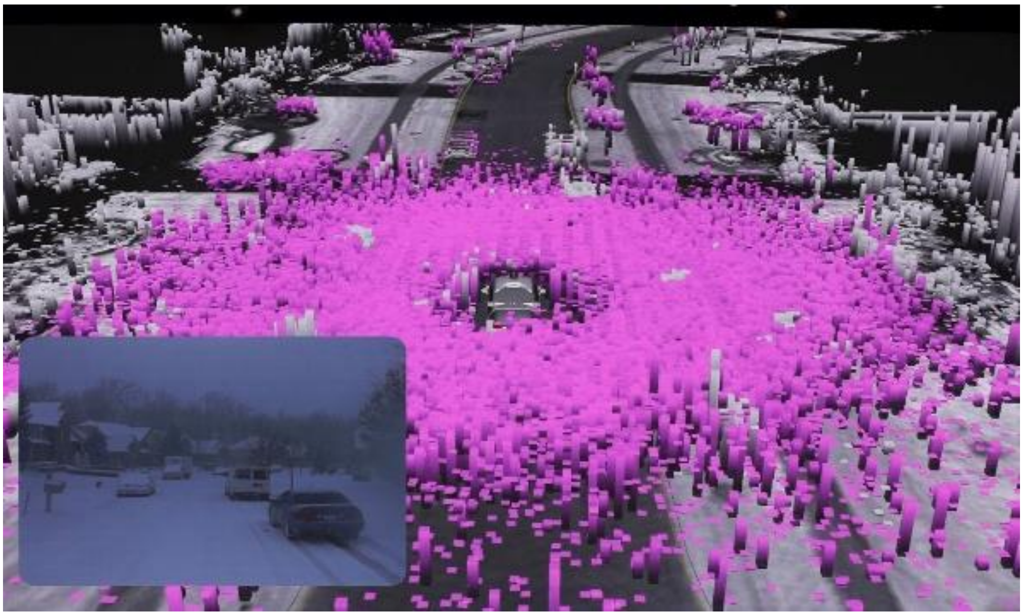

Figure 14: LIDAR rendering of a snowfall - numerous of purple cloud point (source: Waymo)

A common problem for AVs is designing a system that can operate in bad weather conditions. Falling rain and snow tends to corrupt sensor measurements, particularly for LIDAR sensors. Very little research has been published on methods to de-noise point clouds which are collected by LIDAR in rainy or snowy weather conditions. In a project [7] from the University of Waterloo in Canada, researchers have identified a method for removing snow noise by processing point clouds using a 3D outlier detection algorithm. The method is based on the variation in point cloud density with increasing distance from the sensor, with the goal of removing the noise caused by snow while retaining detail in environmental features. Some companies (such as Waymo [6]) are also using machine learning in their sensor system to filter out the snow and see just what's on the road, even if there are vehicles parked by the curb. It is not clear whether the car can distinguish lanes, but such system capabilities could be sufficient to avoid collisions.

Recent trials indicate that thorough testing in a range of weather conditions including heavy snowfall, rain, sleet, fog, smoke, dust, high humidity, heavy winds, frozen road, ground water accumulation or flow conditions is recommended [4].

Road operators need to understand the limitations of sensor systems and filtering capabilities as some conditions may remain difficult to resolve for automation and may require additional physical infrastructure / markers, activities to keep roadways clear of certain obstructions / blockages along with reliable digital mapping to assist during adverse weather conditions.

3.6 Platooning: impact on the infrastructure

3.6.1 Effect of increased vehicle capacity on roads and bridges

Some forecasts indicate the automated platoons of vehicles could increase capacity per lane by a factor of up to 40% when conventional vehicles are excluded from the lane. The shorter the platoon gap and the greater percentage of penetration, the greater the traffic density and road capacity [8].

There is concern on long span bridges carrying closely spaced platoons where the live-load positive bending moment and shear forces may be substantially greater [9]. There may be a need to revisit models that assume dilution of heavy vehicles with light vehicles. Aspects of bridge strength that may need to be reviewed include collision on supports, collision on decks, centrifugal forces on curved decks and braking forces – increasing the strength of bridges must be done strategically (e.g. connect key freight areas suitable for platooning) due to the high cost. Areas that are not suitable may be geofenced accordingly so that platoons dissolve before entering the restricted zone. In some cases, platooning at distances as close as 4m will not result in damage to existing infrastructure, however it may be necessary to revisit axle weights and spacing between successive vehicles when developing policy around the minimum platooning gaps [8].

Pavement fatigue (i.e. rutting) is also a concern, but this may be mitigated by the natural wander of drivers in Level 1 platoons or programmed random wander at higher levels of automation [10]. Each jurisdiction will need to revisit their road design parameters when determining suitable road segments for platooning.

3.6.2 Potential changes to infrastructure design to facilitate platooning

Dedicated lanes could enhance platooning safety since the behaviour of other vehicles would be more predictable, and the platoon speed would be more consistent. Dedicated lanes for platooning could also employ more consistent and advanced lane markings which facilitate lateral control and safe operation at higher levels of automation [8]. Establishing dedicated truck lanes is a potential way to facilitate platooning with minimal impact on existing infrastructure while also enhancing the safety and efficiency of the existing traffic flow. These efficiency benefits are likely to be significantly reduced unless segregated infrastructure is developed [11]. Other highway design changes that could help facilitate platooning include extended passing lanes, modified ramp acceleration lanes, ramp metering and wider pavement markings [8].

However, where road capacity is limited, road authorities must also consider dedicated lanes for public transit needs and public interest objectives must be balanced. The most efficient use of existing roadways may employ dynamically operated lanes that are customized to meet local area needs; use of HOV and HOT lanes for platooning could also be considered.

Consideration may also need to be given to the lengths over which platooning may be effective. For example, highway segments with close interchange or intersection spacing may experience disruptive lane changing or high frequency of changes to platoons that could impact the efficiency of platooning.

3.7 City Planning

The prospect of highly automated vehicles presents both challenges and opportunities with respect to city planning and the way communities grow and develop. The spectrum of private versus shared AV models may have diverse impacts on various community types: wilderness/remote, exurban, suburban, inner ring, urban core.

3.7.1 Urban Sprawl versus Densification

In the urban sprawl model, AVs have the potential to make travel more convenient and comfortable allowing commuters to rest, work or undertake recreational activities and therefore develop an increasing tolerance to longer commute times.

Conversely in the urban densification model, AVs also have the potential to reduce parking needs either through shared mobility models or automated valet service allowing cities to reclaim valuable land used for parking lots and garages and repurpose for housing, pedestrian walkways, cycle paths, green spaces etc.

It should be noted that the urban sprawl and densification are not mutually exclusive and may occur in tandem with growing population needs [12].

3.7.2 Public Transit

Electric low-speed AV shuttles offer the potential to extend public transit and improve mobility to areas that are not well served by existing systems. Automated buses on transit ways could potentially provide cost-effective alternatives to light rail transit. Automated buses operating in a cooperative platoon would offer rail-like service with narrow lane control and optimized acceleration/deceleration with significantly less capital cost [13].

It is recommended that road authorities incorporate CV/AV impact analysis into their planning decisions for new infrastructure and public transit investments.

3.8 MAINTENANCE STRATEGIES

3.8.1 Role of Road Maintenance in Enabling AV Safe Deployment

The condition and legibility of road signs can degrade due to various environmental factors. In addition to traffic sign harmonization, codes and standards development is needed to baseline inspection and maintenance practices as well as establish acceptable thresholds for the extent that pavement markings and traffic signs can crack, fade and deteriorate without compromising machine vision system recognition. The poor state of lane markings, and signage may hinder CAV deployment in affected areas [14].

In rural depopulated areas in Japan, roads are typically very narrow, and there can be vegetation along the roadside. In the example shown in the figure below, bushes were detected as obstacles and the automated vehicle stopped even though it was not a dangerous situation.

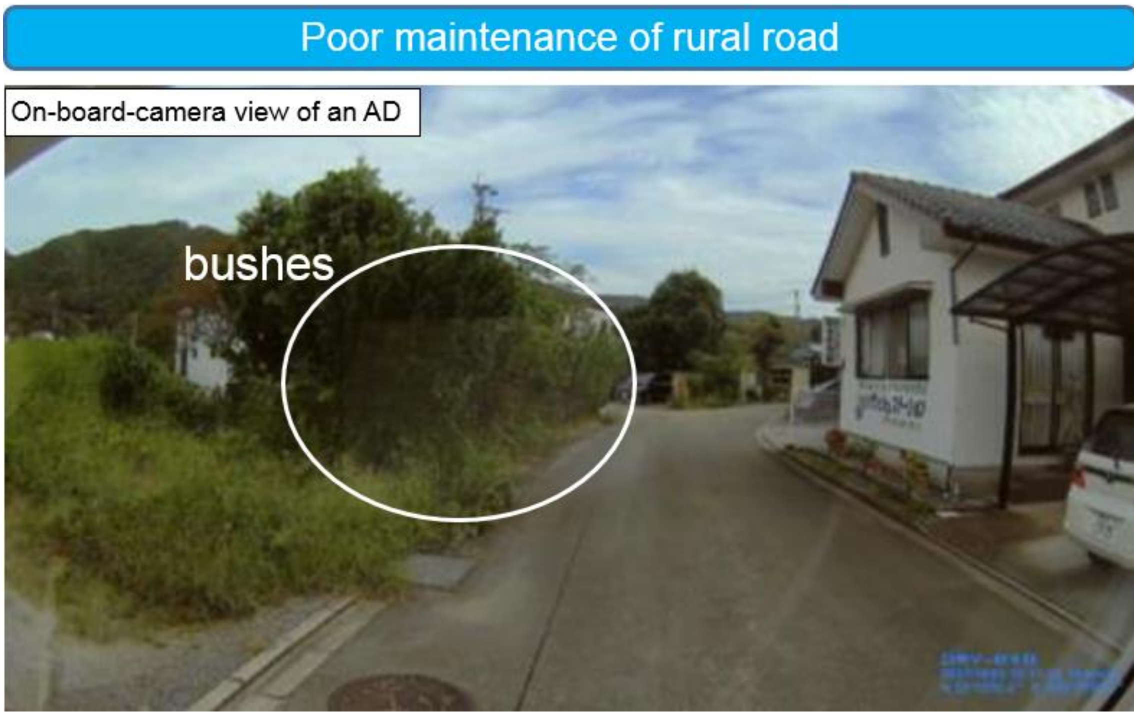

Figure 15 : Bushes visible on street side (Source: NILIM, MLIT, Japan)

The effectiveness and accuracy of TSR systems is affected by the visibility of traffic control devices which can be influenced by rotation, obstruction, deterioration, vandalism, and theft.

In regions with heavy snowfalls during winter, the road width becomes narrower due to piled snow. Thus, 2-lane 2-way roads sometimes becomes 1-lane 2-way roads. Under such conditions, automated vehicles must change their trajectories, or must cope with a “give-way to oncoming car” situation.

Figure 16: Example of foliage blocking a low-speed shuttle landmark [4]

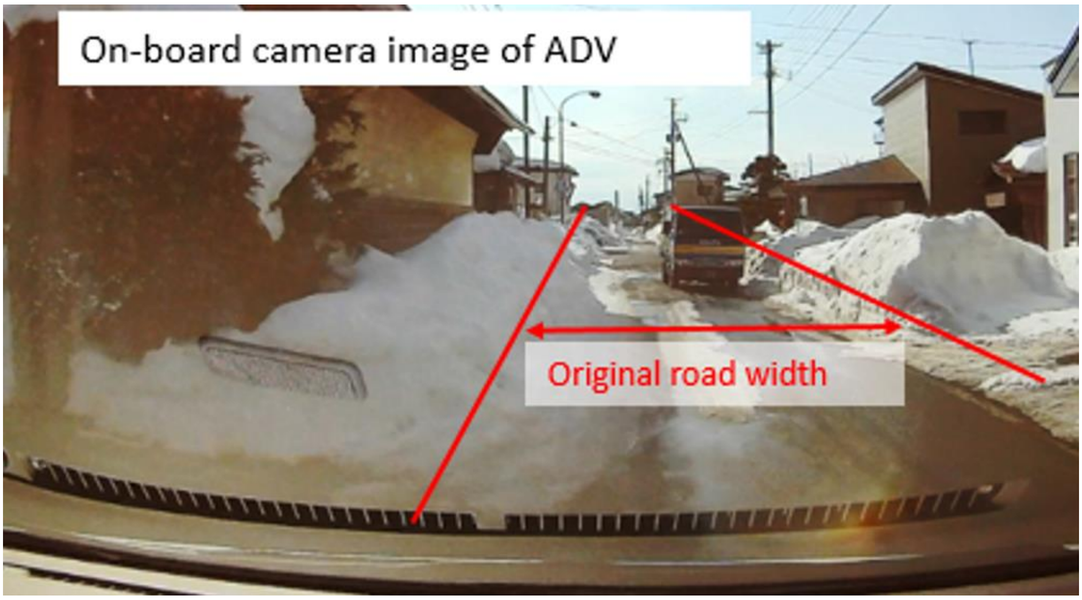

Figure 16: Road width in snowy conditions (Source: NILIM, MLIT, Japan)

It is also important that roads are maintained to be kept clear of natural objects such as overgrown foliage or snowbanks as these may be mistaken for obstacles by machine vision systems and cause AVs to change their trajectories or stop unexpectedly [11]. Landmarks relied on by AV systems (e.g. low speed autonomous shuttles) must also be placed and maintained to be clear from natural obstructions [4].

Figure 17 : Examples of pavement marking and road sign maintenance issues [14]

3.8.2 AV Use Cases to Improve Road Maintenance

There are also opportunities to use automated vehicles for maintenance use cases such as snowplough platooning as well as asset monitoring and repair. For example, cameras and machine vision systems on specialized vehicles can be used to audit signage on road networks [15]. Publicly owned CAVs may also be able to use their sensors and communication functions to report maintenance issues in real time to road authorities [14].

4 DIGITAL INFRASTRUCTURE - CONNECTIVITY

4.1 NECESSITY OF CONNECTIVITY

"Connectivity" means a connection of a vehicle to an ICT terminal via a network, or to another vehicle. Current automated driving technology is mainly based on the sensing systems within the automated vehicle itself, which has many limitations. For example, vehicles alone are:

- unable to effectively detect non-linear line-of-sight and blind spots
- vulnerable to rain, snow, fog, haze and other severe weather
- unable to effectively detect road ice and adjust turning manoeuvres
- limited to a short perception distance
- unable to achieve all-weather automated driving.

The figures below illustrate examples of the ranges within which sensors detect. Sensor recognition systems function within limits - such as range and resolution of detection - connectivity can supplement these limits, enhancing and extending the capabilities of the vehicle. Highly automated driving requires data fusion that integrates various data provided by multiple on-board sensors and from digital infrastructure.

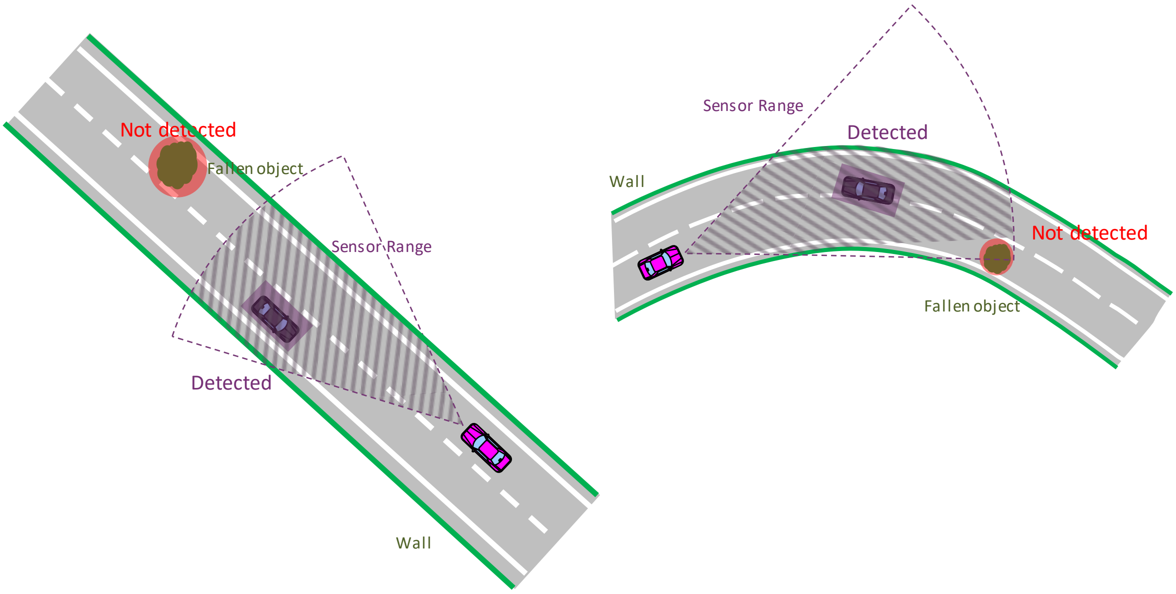

Figure 18 : Limitation of range by sensor detection

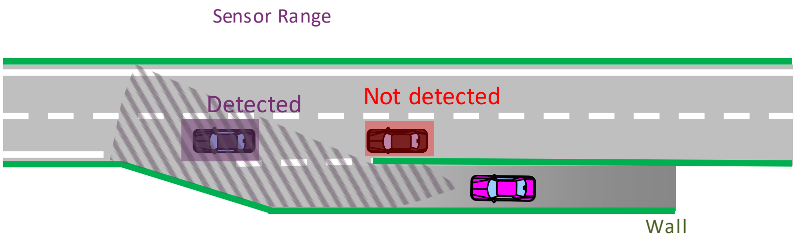

Figure 19 : Information on-board sensors are not able to detect

Data fusion technology, which is defined as the synergistic knowledge from different sources, can assist in creating the overall understanding of a situation and could be a potential solution to sensor limitations.

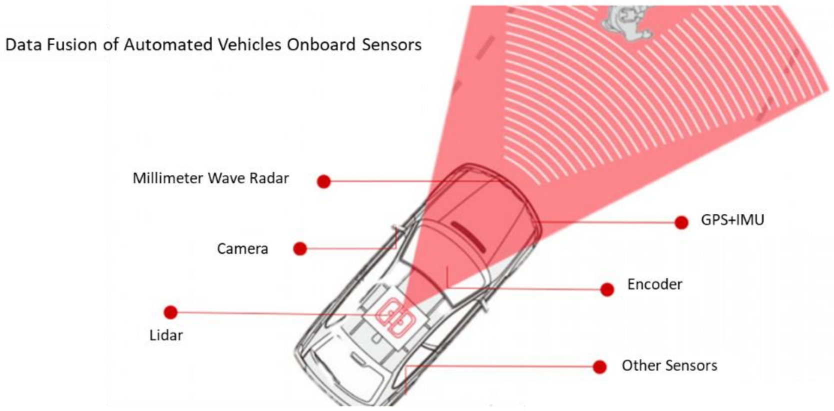

Figure 20: Data fusion [16]

As shown in the figure above, multiple sensors installed in the vehicle enhance detection ability. In addition, the development and deployment of V2X (vehicle to everything connectivity) technologies and infrastructure provides vehicles with the ability to communicate with each other, addressing to some extent the problem of insufficient information that may be available from in-vehicle systems.

Figure 21: Vehicle to Everything (V2X) [17]

4.2 USE CASES REQUIRING CONNECTIVITY

Use cases requiring connectivity from infrastructure (V2I) should be considered separately for high-speed roads (including expressways, motorways, freeways) and ordinary roads due to the differences in travel speed, the presence/absence of pedestrians, bicycles, and parked vehicles on roadways.

4.2.1 High-Speed Roads

Look Ahead Information (LAI) provision service

The LAI is the information of anticipated events which cannot be detected by on-board sensors. The LAI includes the information about the road ahead including, for example, accidents, disabled cars, other obstacles, events, major incident, wrong-way driving, etc.

The National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan is conducting public-private joint research for next generation C-ITS. Regarding LAI, the following information provision services are identified to realize automated driving benefits on expressways. Agencies in other countries are also testing connectivity deployments in their jurisdictions which are discussed included the following sections

Road obstacle information

Since current onboard sensors can only detect obstacles for up to c100m ahead only, it is difficult for automated vehicles to avoid obstacles safely by themselves at highway speeds. With information on obstacles ahead, automated vehicles will be able to change their routes, change lanes, or apply the brakes safely.

It also enables the prevention of secondary accidents and the early opening of lanes by quickly identifying road obstacles. Some car manufacturers operate emergency call service. For example, when the driver's air bag is inflated, emergency information is sent automatically to their emergency call centre. Availability of this information to road operators allows them to respond to an accident promptly.

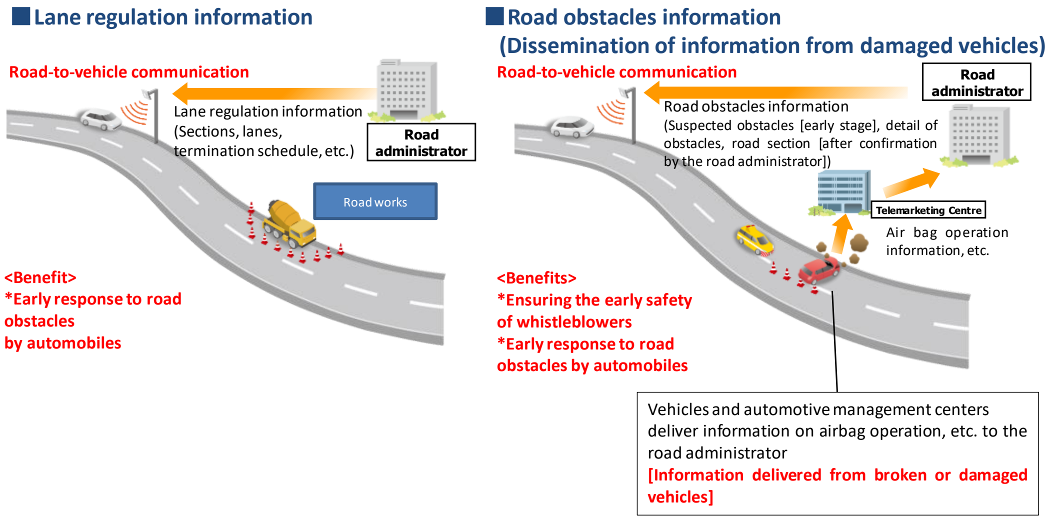

Figure 22 : Road obstacle information provision service

A project on the A2/M2 connected vehicle corridor in the UK tested options for a connected Road Works Warning (RWW) system which communicates information about upcoming roadworks such as the location of roadside workers, the configuration of the worksite, and speed limit requirements for vehicles as they pass the site. It is expected that a system such as this would use a combination of temporary hardware such as worksite beacons and sensors and permanent infrastructure such as roadside communication devices to communicate data about the site conditions to connected vehicles [14].

The Work Zone Data Exchange (WZDx) Specification enables road operators to make harmonized work zone data available for third party use. The intent is to make travel on public roads safer and more efficient through ubiquitous access to data on work zone activity. Specifically, the project aims to provide data on work zones into vehicles to help automated driving systems (ADS) and human drivers navigate more safely.

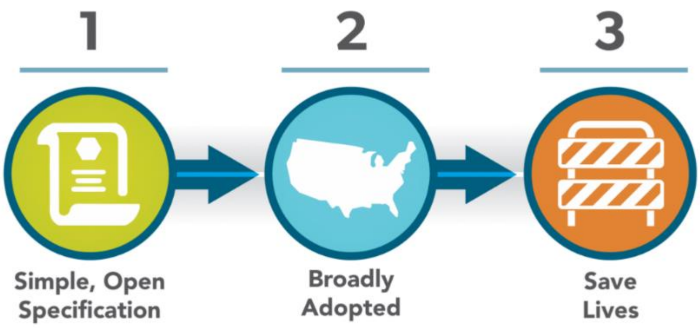

Figure 23: Work zone USDOT Project phases (WZDx)

The U.S Department of Transportation (U.S. DOT) released a $2.4M Notice of Funding Opportunity (NOFO) for WZDx Demonstration, which closed on 3rd August 2020. [18] The purpose of this research program is to increase the safety of the traveling public through the production of consistent public work zone data feeds across jurisdictions. This funding provides public roadway operators the opportunity to make unified work zone data feeds available for use by third parties and collaborate on the WZDx Specification development.

<u>Congestion information</u>

Congestion information provision service sends information to upstream vehicles about traffic jams (congested section, lane end of congestion, etc.) on interchanges and other exits. This information can be used by AVs to enable them to change lanes in advance, either to join a queue if they intend to exit at the interchange or select a free-flowing lane if intending to continue beyond a congested exit.

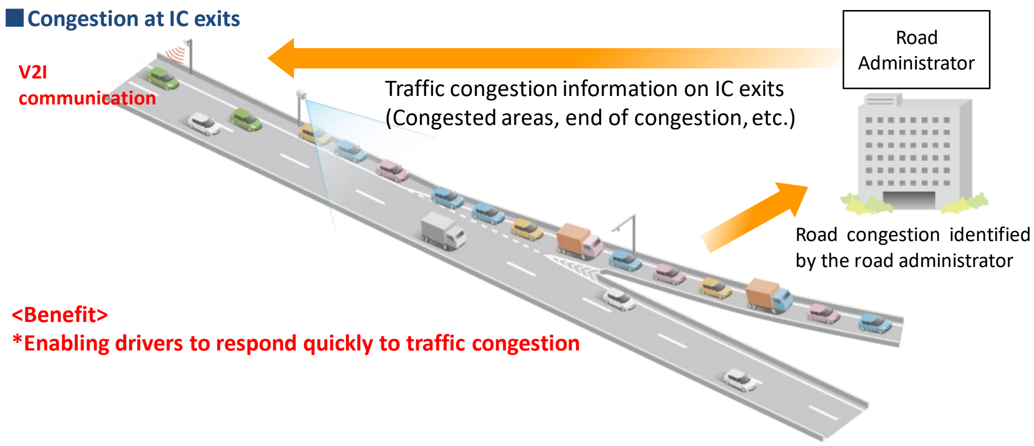

Figure 24 : Congestion information provision service

Tollgate information

Current on-board-sensors are not able to recognize with 100% accuracy which tollgates may be open. Tollgate information provision service ensures reliable gate choice and provides a safer and smoother passage through a tollgate plaza by providing operational information on each lane.

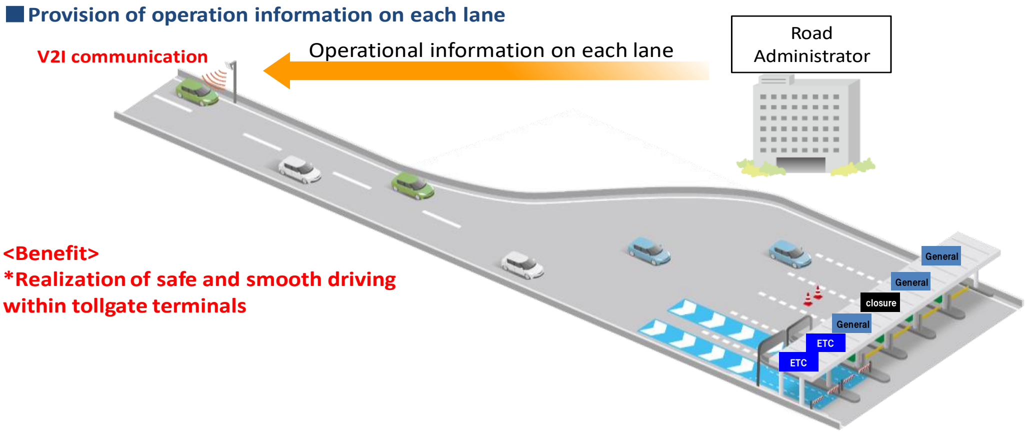

Figure 25 : Tollgate information provision service

Merging Support Service

For merging, automated vehicles need to detect traffic conditions on the mainline, find space for merging, and coordinate their velocity.

Some urban expressways may have relatively short acceleration lanes that may also have constrained sight lines and limit the ability to manoeuvre in the merge area. In order to support automated vehicles to merge smoothly, NILIM is developing a system through public-private joint research which provides information of traffic conditions on the mainline to merging vehicles so that appropriate space to merge smoothly can be identified as automated vehicles approach by adjusting their speed.

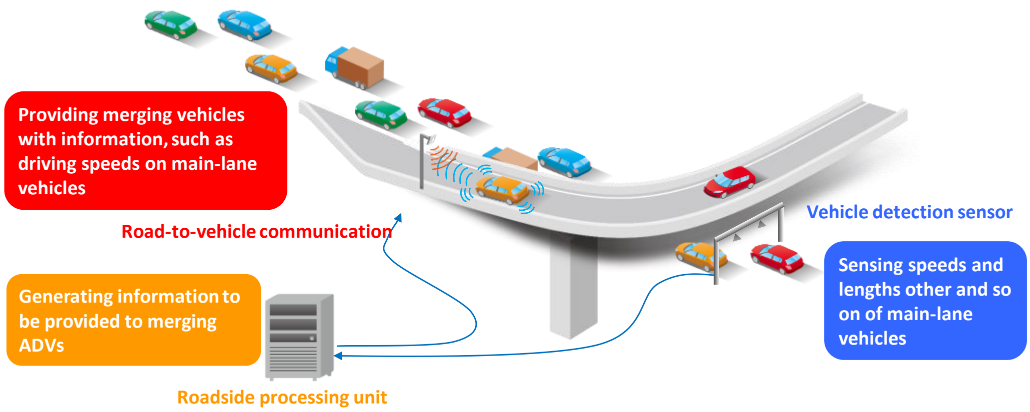

Figure 26 : Merging support service

AutopleX in the UK is a project which enhances an automated vehicle's vision and perception, allowing more efficient and effective traffic merging at difficult lane merge situations and roundabout junctions. The project is investigating the fusion of external vehicle sensor information with map aligned infrastructure-based sensing (sensing all road users) which can be transmitted to AVs in real time, along with the applicable road rules context, via standard Internet of Things (IOT) methods [19].

<u>Intersection navigation</u>

- Left Turn Assist (LTA)

An application where alerts are given to the driver as they attempt an unprotected (or filtered) left turn across traffic (or right turn across traffic), to help them avoid crashes with conflicting traffic from the opposite direction.

Figure 27: Left Turn Assist (LTA)

- Vehicle Turning Right in Front of Bus Warning

An application that warns transit bus operators of the presence of vehicles attempting to cross in front of the bus to make a turn as the bus departs from a stop.

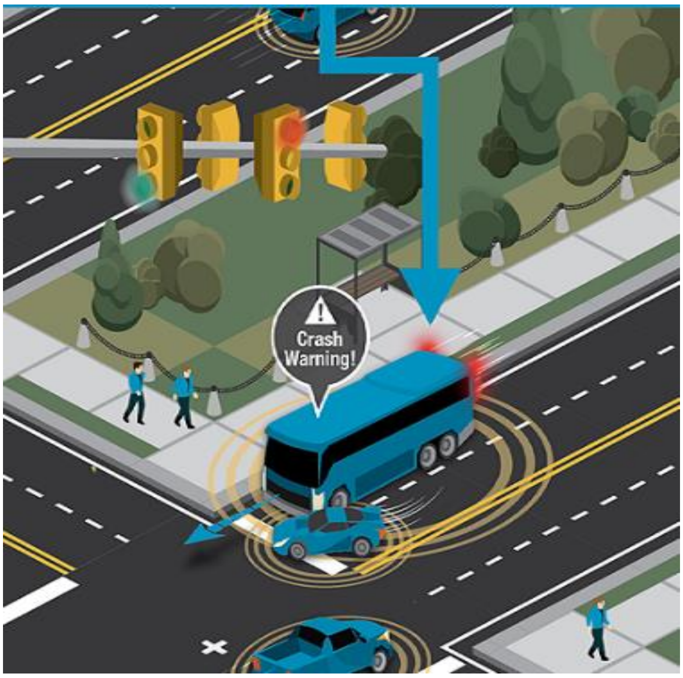

Figure 28: Vehicle Turning Right in Front of Bus Warning

- Red Light Violation Warning (RLVW)

An application that broadcasts signal phase and timing (SPaT) and other data to an in-vehicle device, allowing warnings for impending red light violations.

Figure 29: Red Light Violation Warning (RLVW)

- Spot Weather Impact Warning (SWIW)

An application that warns drivers of local hazardous weather conditions by relaying management center and other weather data to roadside equipment, which then re-broadcasts to nearby vehicles.

Figure 30: Spot Weather Impact Warning (SWIW)

- Queue Warning (Q-WARN)

An application that aims to provide drivers timely warnings of existing and impending queues.

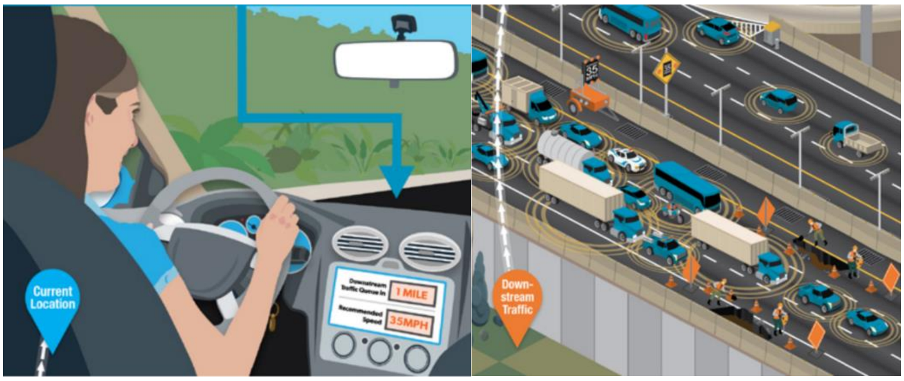

Figure 31: Queue Warning (Q-WARN)

4.2.2 Ordinary roads

Providing information on traffic lights through connectivity has been considered at SIP-adus (the Cross-Ministerial Strategic Innovation Promotion Program: Innovation of Automated Driving for Universal Services) in Japan. Communication of traffic light sates and impending changes is considered superior to conventional on-board cameras since detecting signal states at 100% accuracy has been demonstrated to be difficult under various conditions, including backlight.

Figure 32 : ITS information services at an intersection [20]

4.3 Requirements for connectivity

It is necessary to determine which communication methods are to be used from the available methods as the requirements for connectivity differ for each use case. The following criteria can have different performance requirements for use cases that utilise connectivity:

- Certainty: Whether information is communicated with full precision
- Latency: Delay in sending and receiving communication
- Data rate (MBps)

For example, in merging support, an automated vehicle on the mainline may be required to accelerate or decelerate immediately after acquiring information, and thus, a fit-for-purpose communication method with low latency is necessary. In this example the following steps may be involved to illustrate the steps in the process and the need for high speed communications.

(i) Sensors detect traffic conditions on the mainline.

(ii) The local server quickly generates merging support information. Information is processed locally as quickly as possible to enable AVs to adjust their speeds.

> Edge processing, which can include the execution of aggregation, data manipulation, bandwidth reduction and other logic directly on an IoT sensor or device, may be used because latency of the system is very important. Edge processing is the on-site processing of data rather than sending it to the cloud or a centralised processing server. Edge processing can reduce the amount time taken to provide a processed “answer”, and also reduce the amount of data transmitted by locally calculating the and providing only the required information.

(iii) The roadside antenna provides information about passing time of mainline vehicles at the merging point to AVs with low latency and reliable communication methods.

(iv) On receiving the information, AVs adjust their speeds before entering the mainline to enter the gap in mainline traffic smoothly.

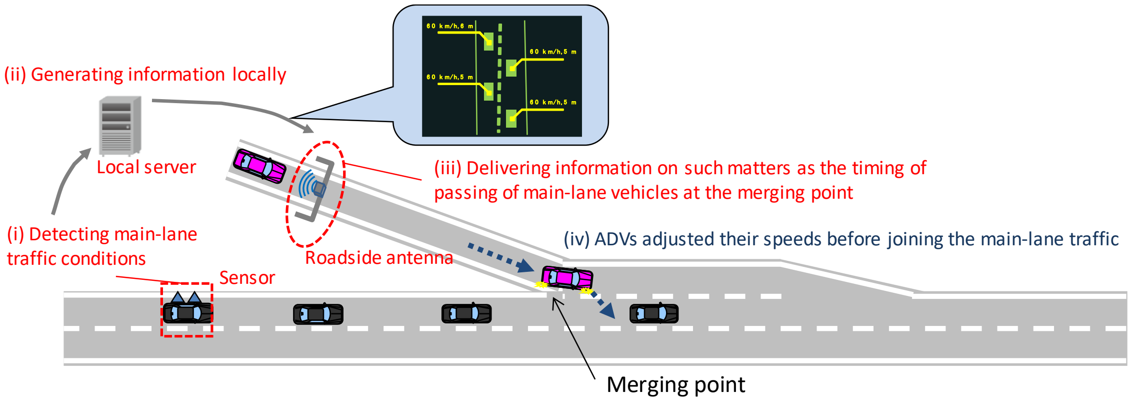

Figure 33 : Concept of merging support service

In addition, road agencies need to take into consideration the costs to deploy connectivity within their jurisdiction including initial investment cost, communication fees and operating cost, and who will ultimately bear the cost.

4.4 COMMUNICATION MEASURES

The communication methods used for C-ITS are classified as follows in the TF B.1 report [21].

- Short Range Communications: 5.8 GHz DSRC, 5.9 GHz DSRC or ITS G5 and incoming C-V2X PC5. The attributes of this category are the short range (geographical distance) it covers, low latency, capability for two-way communication and small data packet sizes delivered.
- Long Range Communications: Cellular networks including UMTS (3G), LTE (4G) and incoming 5G. The attributes are the long-range scope, low to medium latency, two-way communications, and larger data packet sizes.
- Wide Area Broadcast: Digital radio (e.g. DAB+) and analogue radio. The attributes are the long range, medium to high latency, limitation to one-way communication and mid-sized data packets.

For the merging support system explained above (Figure 33 : Concept of merging support service), ETC2.0 is adopted in Japan to develop a prototype. ETC2.0 was adopted as the communication method because the system requires low latency and certainty in communication.

4.4.1 Future communication method

Using 5G technology to achieve collision avoidance and automated driving is similar to using Cellular-V2X, DSRC, and other methods. At this stage it is expected that 5G will have shorter delays and higher reliability. 5G will enable high-capacity data transmission facilitating detailed 3D maps and also the potential to provide remote control of automatic vehicles where authorised.

There are several advanced applications using 5G technology that have been promoted in following areas [22]:

Automated Driving: the traffic information updates could reduce to less than a minute.

Figure 34: Automated Driving [22]

Platooning: Vehicles operate at very close spacing to save fuel and improve the efficiency of cargo transportation requiring high speed and reliable data transmissions.

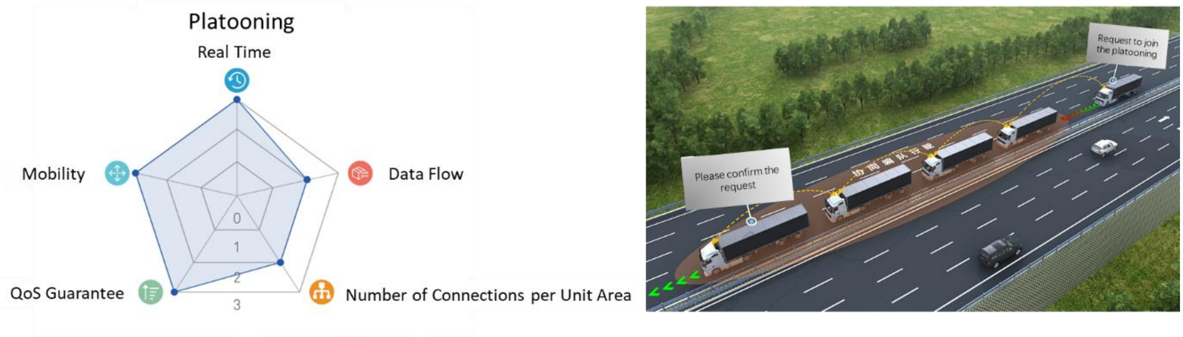

Figure 35: Platooning [22]

Remote Driving: when the E2E delay is controlled within 10ms, the braking distance generated by the remote emergency braking at a speed of 90 kilometres per hour does not exceed 25 cm.

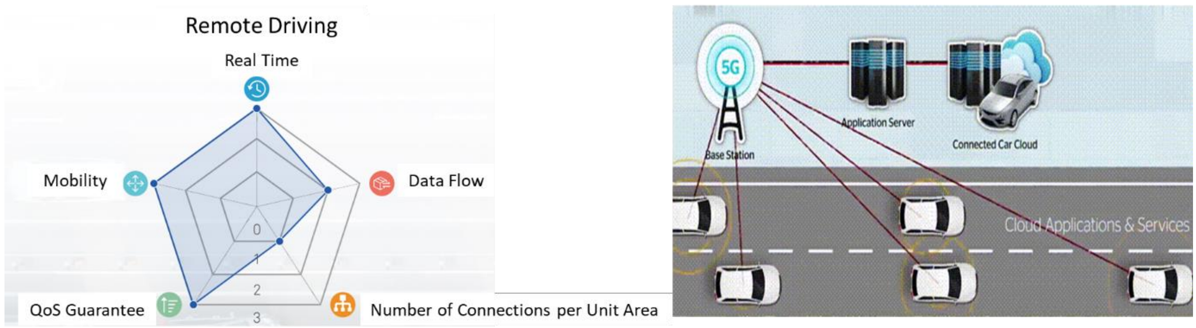

Figure 36: Remote Driving [22]

5G-V2X realized standardization in 3GPP in 2020, which will be followed by a period of a few years of commercial development.

Industry demand plays an important role in 5G technology research and development processes and requirements. Internet of Vehicles has become an important application scenario for 5G. 5G communication technology considers the demand of the automobile and transport industry, and "high reliability and low delay" has become one of the three major application scenarios defined by ITU and one of the four major application scenarios determined by China.

5 DIGITAL INFRASTRUCTURE – DIGITAL MAPS AND POSITIONING

5.1 INTRODUCTION

5.1.1 What is a digital map?

A digital map is a digital representation of a physical environment or asset, combining graphical elements and electronic information to form a virtual representation. They rely on geospatial information – information that has a geographic or locational component - to locate attributes and assets. Unlike a physical map that is fixed once created, a digital map can be updated in real time. Digital maps are built up in layers, using Geographical Information Systems (GIS), where each layer is dedicated to a type of information, such as roads or contours. Users can choose which layers are of interest and effectively remove unwanted detail or information to enable them to better read the maps. As the maps are virtual and electronic, they can be read at any scale. Digital mapping can be obtained from National organisations such as Ordnance Survey (UK), Institut Géographique National (France), National Geographic Information Institute (NGII) Korea. These digital maps can be considered as the “base maps” and are similar to the more traditional paper map, showing a digital representation of the physical environment. These base maps are useful for wayfinding and navigating from A to B. Commercially available navigation systems used in vehicles (e.g. satellite navigation or satnav systems) rely on digital maps to calculate the optimum route to travel; various parameters such as “fastest route” or “avoid tolls” can be programmed in to these systems.

A more sophisticated level of mapping is the high definition (HD) map which includes additional data such as lane markings, signs, speed restrictions and road rules [23].

Current generation in-vehicle navigation systems use HD maps and live traffic information, including social media content, to predict the optimum route. Even these systems rely on a human driver to correct for any discrepancies within the data set, road network operators do not accept liability for errors [24].

5.1.2 Why digital maps matter to AV

The safe and efficient operation of an AV relies on:

- Navigation – understanding in real time where the vehicle is in relation to its intended destination
- Road positioning – guiding the vehicle on the road and in relation to lanes
- Driving in traffic – understanding the relative position of other vehicles and road users and driving appropriately to avoid collisions.

Whereas sensors provide real-time visibility in the vehicle’s immediate proximity, maps confer a wider view that allows vehicles to anticipate potential critical situations from the surrounding environment. The real challenge for HD map generation is the current level of fragmentation in the automotive industry together with the lack of standards. The concept of a Local Dynamic Map proposed by Shimada et al [25] illustrates the various types and levels of data and information that connected and autonomous vehicles may require for safe operation.

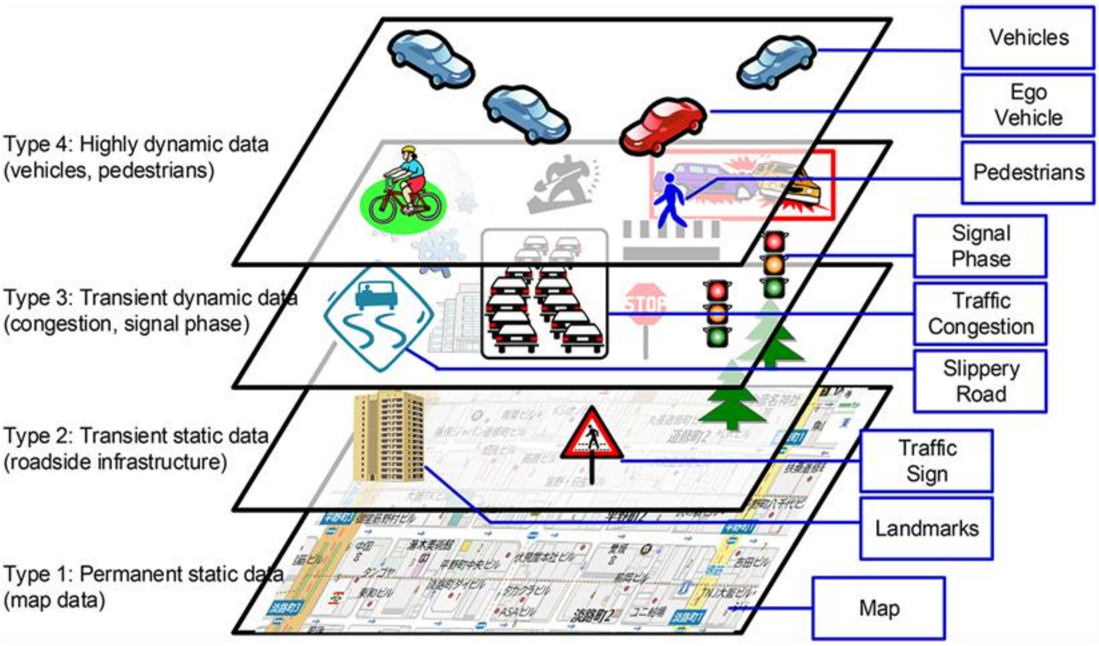

Figure 37 Level model of a Local Dynamic Map [25]

Navigation – (Types 1 & 2) the operation of an AV relies on the ability of the vehicle's control systems to safely navigate from origin to destination on a road whilst interacting with road infrastructure, other vehicles and road users. Satnav systems rely on digital maps to plot a route and then to track the location of the vehicle in transit, checking that it remains on the desired route and re-routing when required – due to a reported incident for example, or where the vehicle takes a wrong turn. In this navigational process, the vehicle relies on GNSS (Global Navigation Satellite Systems) to match the vehicle's position to the digital map. Many navigation system providers update their maps using data from vehicles using their application via Application Program Interfaces (APIs). One outcome from this approach is that different providers may use different variations of the base mapping, losing a "single source of truth".

Road positioning – (Types 2 & 3) the safe and efficient operation of an AV requires the vehicle (and its control systems) to understand where it is and to manoeuvre safely using on-board sensors to detect the environment and "see" features such as road marking and signs. An AV uses a variety of systems to understand where it is in relation to the road – sensors such as Lidar, digital maps, magnetic guidelines/markers, and Global Navigation Satellite Systems (GNSS) are used in various combinations.

Driving in traffic – (Types 3 & 4 data) safely negotiating traffic and other road users relies on a sophisticated array and combination of on-board sensors to understand a highly dynamic and complex environment rather than a digital map which is relatively static.

Some advanced driver assistance systems (ADAS) and Highly Automated Driving systems rely on mapping to augment the information from their sensors [26]. It is unlikely that current technology will enable fully automated driving without using data from digital maps to support or supplement on-board sensors and positioning systems – this will increase reliance on connectivity to facilitate V2I communications [23].

5.2 Digital Map Standards

5.2.1 Base Map

The base maps are those provided by the National or State mapping organisations – including Ordnance Survey (OS) in the UK, Institut Géographique National (IGN) in France, National Geographic Information Institute (NGII) Korea. Users can subscribe for automatic updates to the base map. Base maps themselves are not useable by AVs for navigation – unlike a human map reader – and rely on their conversion to the relevant digital standard that the AV can "read" and use. Base maps are used by commercial organisations (such as navigation and wayfinding providers) to produce their own mapping systems for use in vehicles.

Different standards for digital mapping are used in different countries – the European Commission's INSPIRE programme aims to create standardization for mapping [27].

5.2.2 Ownership

Taking the UK example again, the ownership of the base map belongs to OS.

5.2.3 Changes to the base map

Permanent changes are provided by the originator of the map, as mentioned above this can be accessed via subscription. Dynamic or temporary changes can have a significant impact on the operation of AVs, such as road works, changes in lane use (e.g. a bus lane) etc. since they are not included in the changes to the base map and require either a Digital Twin or a High Definition map. An important consideration for road operators and AV users/operators is the availability of proposed changes to road layouts and how quickly they can be implemented to the map so that the AV recognizes the change as soon as it happens [28]. Most current navigation systems do not include automatic updates to maps which can be frustrating for human drivers but not generally unsafe, however real time synchronisation between digital and physical information is essential for the safe operation of AVs. The European Commission TN-ITS INSPIRE [29] programme aims to provide a platform to enable road network operators to publish changes to their networks so that map makers and service providers can update their maps and make them available to AVs.

5.3 Digital twin

5.3.1 Definition

A digital twin is "a realistic digital representation of assets, processes or systems in the built or natural environment " [30]. In the context of a road network, a digital twin is built upon a digital model of the road and all its attributes – signs, markings, structures, drainage, fences, etc. Rather than being a static model, a digital twin is linked to the physical asset using live data flows from sensors which input current performance data from the physical twin and feedback into the physical twin via real-time control. Therefore, the digital and physical are twinned in real time.

Digital twins can exist at any scale, from a street to a city to a national road network.

Digital twins are useful for road network operators when designing, constructing, and maintaining their networks, however it is unrealistic to expect digital twins to be created as a retrospective exercise; the cost of digitising existing networks would be prohibitive. As the use of digital tools becomes commonplace new and upgraded roads will increasingly have a digital twin.

5.3.2 HD Maps

HD (High Definition) maps are like digital twins in that they contain much more information than a standard digital map – lanes, signs, road markings, speed limits and other traffic restrictions. HD maps make available layers of information and detail to support and enable AV operations. Commercial organisations have created products to develop and sell HD mapping. The Austroads project team was unable to find commercially available HD maps of Australia or New Zealand in 2019 [23]. The researchers concluded that the lack of commercially available maps was likely due to a lack of market demand.

The use of HD maps and digital twins is an emerging area and the standards and responsibilities for generation, owning, updating, and publishing are also emerging.

5.3.3 Interaction with AV

A digital twin will improve the reliability of AV operation by enabling a digital interaction between the information contained within the twin and the AV, rather than relying on sensors to read, process and understand information on physical signs and markings. As the penetration of AVs increases towards 100%, the role of signs and markings for traffic control becomes increasingly redundant. This does not, however, apply to pedestrians, cyclists, scooters, and other modes and would require further investigation into the management and operation of a multi-modal transport network with varying levels of automation across modes.

5.4 Positioning

5.4.1 Satellite positioning

Global Navigation Satellite Systems (GNSS) are used to determine the location of a vehicle fitted with an appropriate receiver, using signals from satellites. Satellite Navigation has a central role in the technology-mix that is currently needed to perform the level of positioning required by automated vehicles; in a recent inquiry made in EU among pilot projects, it resulted in all of them are making use of GNSS as well as fusing GNSS positioning with several other on-board sensors. Since GNSS, as well as other on-board sensors, is affected by external conditions, it is essential that a high quality GNSS is used; this requires optimisation of some key parameters such as availability, integrity, accuracy, sensitivity and robustness to interferences by exploiting all the new GNSS signals/services and recent receivers' development (e.g. dual frequency).

GNSS is an established technology providing absolute positioning, irrespective of weather conditions. GNSS is independent of any sensors based on perception and may resolve any ambiguities from sensors. It provides accurate timing information, which is needed for sensor fusion, to synchronize the output data of the on-board sensors. Although GNSS could function stand-alone for the less automated functions, there is a continuous influence of environmental conditions and local errors. Therefore, GNSS working in a complementary and interoperable manner with other automotive technologies is essential in all the levels of automation defined by the industry.

Space Based Augmentation Systems (SBAS) are also used to deliver the positioning requirements for AV [28].

Galileo

In Europe, policy makers understood that Galileo, the European GNSS, could better support automated vehicles for cooperation between vehicles and for better positioning. The 2016 Declaration of Amsterdam worked to address these barriers and developed a shared European strategy on Connected and Automated Driving. Most recently, the European Parliament adopted the European Strategy on Cooperative Intelligent Transport Systems (C-ITS) in March 2018 in which Galileo also has a critical role.

Australia & New Zealand

Free access to an SBAS is not available in Australia nor New Zealand [28] which has the potential to be a barrier to the operation on AVs. The solution could be a hybrid system using GNSS and other, ground based, positioning technologies. The result would be a requirement for different hardware on vehicles in these markets which may not be commercially viable.

5.4.2 Level of accuracy required

The level of accuracy required for automated driving depends on the level of automation:

LEVEL 2 - Partial automation:

- The positioning requirement of basic ADAS functions is at metre-level accuracy (in the range of 2 – 10m)
- The GNSS solution meets these requirements complemented by inertial navigation, odometry, and dead reckoning.
- Type of GNSS solution: normally single frequency receiver (recently multi-GNSS)
- LEVEL 3 - Conditional automation:
- The positioning requirement of Advanced Cruise Control functions is at half metre-level accuracy (in the range of 40 – 50cm)
- The GNSS solution meets these requirements complemented by radar and ultrasound sensors, eHorizon, Computer Vision and Simultaneous Localization and Mapping (SLAM)
- Type of GNSS solution: from single to double frequency, more accurate code measurement augmented by Differential GNSS (DGNSS) and SBAS.

LEVEL 4 – High automation:

- The positioning requirement of Autonomous Driving functions is at decimetre-level accuracy (in the range of 25 – 45cm)
- The GNSS solution meets these requirements complemented by similar sensors of Level 3 and by 3D Maps, V2V and V2I communication.
- Type of GNSS solution: from double frequency to triple frequency, high accuracy carrier phase measurements including Real-Time Kinematic (RTK) or Precise Point Positioning (PPP), or a combination of both, and authentication encryption

LEVEL 5 – Full automation:

- The positioning requirement of fully Driverless functions is at decimetre/cm-level accuracy
- The GNSS solution meets these requirements complemented by similar sensors of Level 4, and by machine learning and artificial intelligence.

- Type of GNSS solution: as level 4, but guaranteeing more robustness from multiple frequency, enhanced authentication, better availability and very efficient high accuracy / high integrity solution.

5.4.3 SF-PPP

Single Frequency Precise Point Positioning (SF-PPP) uses a low-cost receiver with a single frequency, single antenna and single GNSS constellation to provide greater levels of positional accuracy for AV. This has been shown to achieve accuracy of 50cm [31]

5.5 Satellite blind spots

GNSS positioning relies on line-of-sight from the vehicle to the satellite(s), therefore when a vehicle is within a tunnel the link to the satellite is lost and the vehicle is no longer able to communicate and establish its position. There are various technical solutions designed to overcome the problems within tunnels to maintain positioning information whilst the vehicle is out of sight of satellites. Thus, GNSS is normally assembled with an Inertial Navigation System (INS), map-matching and dead reckoning techniques. The navigation in tunnels is also supported by the information provided by radar, video sensors or differential corrections from terrestrial stations technologies.

The same problem occurs in some city situations where high-rise buildings create “canyons” where satellite signals cannot reach vehicle-based receivers, driving within multi-story car parks or basement car parks presents the same problem. In this case, the use of multifrequency GNSS signals can be an appropriate solution to substantially reduce the consequences of reflection in buildings (the so called, “multipath effect”) that distorts the positioning calculation.

6 DIGITAL INFRASTRUCTURE – DATA ISSUES[1] COMMON TO CONNECTIVITY AND DIGITAL MAPS

Digital Infrastructure is the digital representation of the road environment required by Automated Driving Systems. It includes the connectivity between the vehicle and the road infrastructure, the positioning infrastructure, digital maps and links to advanced Road Management Systems. [32]

The role of digital infrastructure is to provide:

- Support for internal procedures
- Services to external users, including traveler information services
- Support to connected and automated vehicles.

It is expected that automated vehicles as well as automated functions supporting in-vehicle ADAS will need to be supported by additional digital data and services provided by Road Network Operators. In this respect it is important to understand the basic logic of ADAS functionalities. A vehicle uses data from several in-vehicle sensors (including cameras, lidar and radar) and merges them with external data, e.g. map data provided by a map-service-provider or data received via C-ITS interfaces. In a so-called “perception phase” all aggregated sensor data are used to build objects resulting in a situational analysis. All data is interpreted to create an “environment-model” which forms a basic requirement for the in-vehicle decisions to activate or deactivate specific automated functions. If automated functions are activated, the “environmental-model” is aligned with the Operational Design Domain (ODD) where automated functionalities are activated.

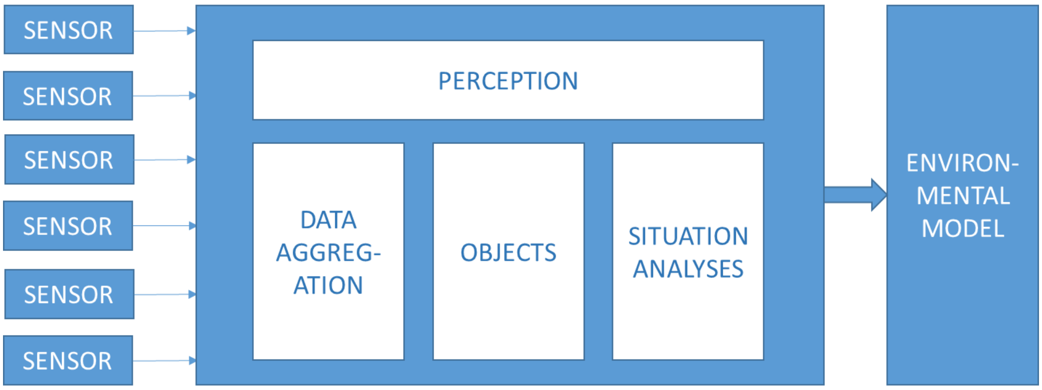

Figure 38: In-vehicle process to create an environmental model

In the context of the “perception phase”, data from road network operators are highly desired to support automated driving tasks. In addition to the basic data requirements in Europe, a discussion is currently ongoing regarding support for automated in-vehicle functions in case of events, such as poor weather conditions, roadworks, or other incidents on the road network. The so-called “Infrastructure Support levels for Automated Driving” (ISAD) focus on mixed traffic conditions and define the level of support for ADAS as well as for non-equipped vehicles to enable all vehicles within the road network to be supported with respective services. These levels can be used to classify the road infrastructure

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[1] See also PIARC report “Road related data and how to use it” published in December 2020

for the supported vehicles, both automated as well as conventional. A “level E road” provides no infrastructure support, whilst a “level A road” provides full support for ADAS functions via digital information and by physical infrastructure such as variable message signs (VMS) for conventional vehicles. It is expected that, based on the information received from the road network operator, a vehicle will decide to activate/deactivate an automated driving function.

				Digital information provided to AVs			
	Level	**Name**	**Description**	**Digital map with static road signs**	**VMS, warnings, incidents, weather**	**Microscopic traffic situation**	**Guidance: speed, gap, lane advice**
Conventional infrastructure	**E**	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
Conventional infrastructure	**D**	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	**C**	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
Digital infrastructure	**B**	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
Digital infrastructure	**A**	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

Figure 39: Levels of the Infrastructure Support for Automated Driving [33]

It is evident that not all roads will provide the same range or quality of services to road users, different segments along a road will provide different support levels. Bottlenecks and safety critical road stretches and junctions will likely provide greater AV support, while more traditional support will likely be given along rural and remote roads and in peripheral areas. Such scenarios also reflect the current situation, where a better physical infrastructure can be expected, for example on motorways than on rural mountainous roads in woodlands. Figure 40 shows, what such an ISAD road classification may look like. The ISAD level information for all road stretches needs to be described to provide the operating environment information to in-vehicle systems and associated service providers. Accordingly, drivers would be informed what services they can expect on what road-links.

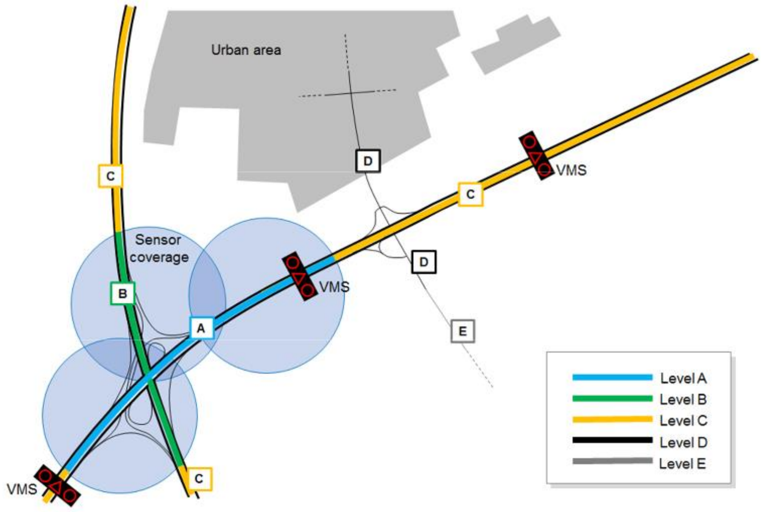

Figure 40: Examples of ISAD levels along the road network [33]

The following sections further expand on the detail of the digital elements needed to support ADAS functions by road network operators, specifically in relation to the processes for data processing and data management.

6.1 Data Management for Road Network Operators

If a road network operator intends to provide digital information into vehicles, proper processes need to be established in addition to the technical systems and equipment required. PIARC Task Force B.1 published a technical report on "Big Data for Road Network Operations" [21], describing the framework for big data management and usage based on global best practice. Specifically, big data management deals with capabilities to process big amounts of data and to perform proper data analytics using Artificial Intelligence (AI) and machine learning techniques. To facilitate the setup of a digital infrastructure, skills on big data, AI, Internet of Things (IoT) etc. are highly beneficial to road network operators to provide accurate and trusted information into a vehicle. Setting up proper data analytics procedures will result in highly valuable services supporting ADAS functions. The provision of services with high quality timely content, with accurate positioning information (even with lane specific detail) will undoubtably be used in vehicle systems.

6.1.1 Requirements on data

There are mainly two kinds of data to be used by automated vehicles, static and real-time. Static data provides a general description of the road characteristics as well as the legal requirements, (e.g. road rules and general user priorities for making decisions). Real-time data provides accurate information on current road conditions, incidents as well as current active regulations (e.g. variable speed limits or dynamic lane restrictions). "Known quality" is a fundamental requirement for both types of data. Smart data is defined as structured accurate data with known benefits that serves specific use-cases.

The ownership and basic resources of data used to support ADAS functions need to be resolved. It is important to know where data comes from and who owns data provided. Only if the resource is known and validated can data be used for digital infrastructure support.

For the data itself a structured dataset is of high importance, where raw data are structured in a way that spurious outliers are eliminated. False data needs to be eliminated, and only trustworthy data used in the dataset that forms the basis for RNO services supporting ADAS functions.

The purpose of original data collection also needs to be understood, especially when it is possible that collected data could be reused for other purposes, e.g. to support ADAS functions. Data collected from a road junction (i.e. intersection) for traffic planning issues may have an inherent aggregation level within the collection process which cannot be easily disaggregated. The quality of such data may not suit the needs for other uses that require more disaggregated information (e.g. where lane specific information is needed). As a result, data that has high quality for one purpose might have low or even no quality for another use case. For the support of ADAS functions, it is important to be clear on the potential utility of pre-existing data, especially regarding safety, efficiency, environmental guidance, or law enforcement.

For the reasons outlined, a corresponding and clear explanation of datasets is needed, referred to as metadata-information. Metadata ideally describes the content and structure of data as well as the primary purpose for which data has been collected. In this regard the European Commission has published the DCAT-AP (Data Catalogue Vocabulary – Application Profile) specification for Metadata [34], which provides guidance to describe datasets in a harmonised structure. That specification is used as basis for data access at European Access Points for transport related data [35].

6.1.2 Data processing and data management

Data is the basis to enable new services, such as those for automated vehicle support services. However, raw data has only a marginal benefit or limited useful value by itself. Usually data needs to be processed to create new information or combined with other complementary data to improve existing services. This service generation by a road network operator level is done in integrated, holistic traffic management centres. Therefore, it is highly important to set up internal processes as well as technical expertise to process data in real time to enable highly reliable and quality support to ADAS functions within equipped vehicles.

In setting up proper data processing mechanisms it is important that the resulting services will not only serve automated vehicles, but various interfaces to internal and external stakeholders that need to benefit from improved service quality. These services with improved quality will not only support internal asset management and planning issues but also assist external stakeholders that can benefit via a broad range of services, as shown in Figure 41. This provision of services via different interfaces needs to be supported by proper data management structures where both internal and external users need to have access to the same data stack through appropriate agreements and controls. Such infrastructure needs to avoid the duplication of data or the provision of similar data with opposing content and with different quality.

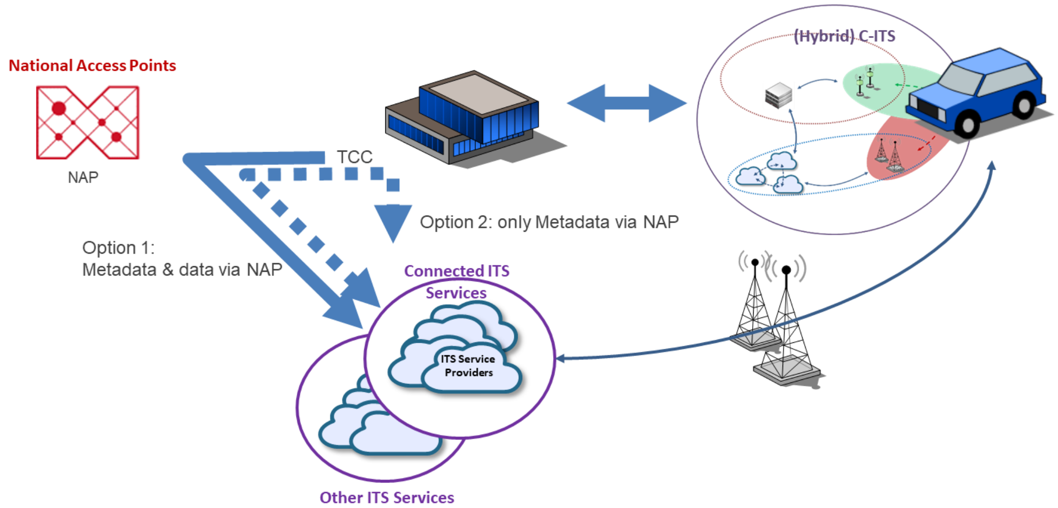

Figure 41: Stakeholders in RNO data exchange [36]

Within Figure 41 the focus is on data and service provision from road network authorities towards external stakeholders, including connected and automated vehicles. The traffic management centre (TMC) (or traffic control centre (TCC) as shown in the figure), operated by a road network operator, processes all data and provides access to the data as well as to improved services via different interfaces. All external stakeholders are served by the same, central system. In this example, data can be provided via National Access Points (NAP) (Option 1), which is a European obligation to be set up in EU-countries. ITS Service Providers can access this data via the NAP., Alternatively, the NAP may only provide a catalogue type service based on metadata which re-routes the request to the road network authority, in which case data access could be given directly by the road network operator (Option 2). An ITS Service Provider could then use the data received for their own services, e.g. traveller information or navigation services.

In addition, the TMC (or TCC) can also exchange data and services with connected vehicles using their own C-ITS infrastructure. C-ITS services can rely on direct short-range communication or via cloud services for long-range communication using cellular networks as an example. It is important to reiterate that whatever interface is used, data exchanged or transmitted always needs to come from a central data management structure set up at the TMC (or TCC) of the road network operator.

It is also expected that data collected by vehicles will also be accessible for use by road network operators. Single vehicles could serve as moving sensors improving data and service quality of the road network operator. This data exchange and access to data opens several additional questions regarding data access in general and specifically on data usage, legal aspects, and cost of data.

6.2 Data Access

To enable the proper usage of data for traffic management purposes, as well as for the creation of services to support ADAS functions, access to data is crucial. The use of standardised data exchange interfaces, based on universal standards, is highly recommended. Such standardised interfaces enable easy access and use of data without intermediate complex conversion processes, as during conversion processes data elements and critical knowledge might be lost. Proprietary interfaces are mainly used to strengthen a direct dependency between a data-provider or component supplier and a data-user.

However, in a quick moving world the use of standardised interfaces is highly recommended to ensure flexibility in terms of business-relations, even after the installation of components or the establishment of cooperation. Additionally, further data providers that contribute to new levels of quality, or the creation of even new services, can easily be added by using a standardised data exchange interface.

Alongside the technical aspects of data quality, access and use, several other issues related to business and legal aspects need to be considered, when discussing data access and use. Liability issues, in particular, are developed in [Austroads Report (AP-R581-18) Section 2.1]

6.2.1 Willingness to give access to data

Data has a monetary value. In principle all actors need to be sensible when sharing data and giving access to third parties. Usually, data sharing is based on cooperation models between different actors that clarify the content of data, based on metadata descriptions, and the commercial contract details. Prior to further discussion of cooperation models, data access principles relating to different actors in the domain of automated driving need to be discussed and agreed.

<u>Data owned by road network operators</u>

In many cases road network operators are public entities and need to follow national regulations on data access. In many areas, public data are treated as existing for the public good generally resulting in an open data policy. In Europe, for example, several European regulations define the access to data owned by public entities. Sometimes there are only very generic regulations for all kinds of public data, but there are also regulations in the transport sector defining data categories that need to become publicly available. These regulations are aimed at giving access to public data by private companies for the generation of new services. So, usually road network operators are obliged to give access to their data based on a marginal cost principle. This marginal cost principle can also be used for service provision by the road network operator.

Currently most road network operators are not willing to provide any guarantee (thereby limiting their liability) for any supplied data [37]. This is especially the case as current legislation for safe road network operations (in most if not all jurisdictions) still considers the physical infrastructure, including signs and road markings, to be the regulatory element. The need for operating a digital infrastructure that provides regulations in a digital machine-readable format, including the digitalisation of the national road traffic acts, may be required for higher automated in-vehicle functions. In this regard standardisation bodies have already started to work on the management of electronic traffic regulations (METR); liability issues towards road network authorities might arise in the future.

<u>Data owned by private actors</u>

Private actors associated with automated vehicle operations include vehicle manufacturers, telecom operators, digital map providers/operators, and other C-ITS service providers. Usually, private actors are not directly affected by national legislation on data provision. This is due to data and services provided by private actors being incremental parts of their business development and product offerings. Therefore, private actors are in principle very careful in allowing access to their data. This can prevent competitors from providing the same service quality, allowing a product developer to maintain a legitimate market advantage based on their investment. Few companies are likely to be willing to share their data – to avoid their competitors gaining insights into their current development status.

For automated vehicles, data exchange of specific types between different actors and vehicles of different brands will be a pre-condition for their successful deployment. Vehicle-to-Vehicle communication, where one vehicle informs the other on possible dangerous situations, is highly relevant and requires a level of collaboration and data exchange. Currently it is not defined what kind of data will need to be exchanged between different vehicles for a normal driving task, and what data will be generated by in-vehicle systems. For vehicles travelling at high speed in a mixed vehicle environment, vehicle-to-vehicle data exchange will be of high importance to enlarge the operating horizon of a single vehicle. Current in-vehicle sensors provide an overview of a vehicle's surroundings up to approximately 300m ahead. For a vehicle travelling at 120 km/h, it would potentially have a reasonable overview of the upcoming conditions within the next 9 seconds, depending on traffic and environmental conditions. The relative shortness of this period might result in sudden uncontrollable movements that could be experienced in non-harmonised traffic flows. Exchanging data between single vehicles would drastically enlarge the potential operating horizon enabling safer vehicle operation and more efficient traffic flows.

Road network operators would benefit from data generated by private actors. If, for example, static geometry data provided by road network operators are not accurate enough, a feedback loop from private actors concerning an alteration to the geometry would help all actors in the domain. Dynamic data related to efficiency or safety are of high relevance for road network operators. Privately generated data could help operators to improve maintenance processes. Currently data of this kind held by private actors is hardly accessible for reasonable costs, mainly based on business issues, where other private actors might also unfairly benefit from services based on this data.

However, where public welfare is concerned, such as the safety of road users, there may be a need for legislation on data access that needs to be followed by private actors. One example is with emergency calls, where vehicle manufacturers need to provide access to data concerning accidents via telecom operators to emergency services.

A similar situation concerning safety is now emerging in connected vehicles. In Europe, legislation exists [38] that identifies categories where private actors need to provide access to data for free. This includes categories such as the identification of a slippery road surface or the identification of wrong-way drivers. In such cases, private actors are obliged to provide access to their data, if it contributes to the enhancement of road safety.

Data owned by individuals

In principle, it is the individual that must decide whether the data generated by their vehicles can be forwarded and used. [39] However, usually the individual has only limited influence on their data – when signing a contract (e.g. for a vehicle or for a mobile network operator), the rights on data usage is also generally handed over to the manufacturer or service provider.

Alternatively, when considering connected vehicles where vehicles exchange data with vehicles or infrastructure, it is foreseeable that the vehicle owner may decide whether to provide access to in-vehicle generated data. This principle is followed in Europe [40], where the owner of the vehicle needs to give their consent to the use of data and to whom it may be given, including the specific purpose for the use of data and hence for the identified service. It foreseeable that there will always be an opt-out option for end customers and data subjects.

Based on this general principle it is important for road network operators to inform travellers about the purpose for which their data will be used. The willingness of travellers to accept a reduced level of privacy will likely increase if a clear reciprocal benefit is perceived. To make the road safer or to improve efficiency might be good argument to convince drivers to provide access to their data. In parallel the supporting services need to be exposed and made understandable for road users. For other service categories (such as law enforcement), national legislation needs to be prepared as most drivers would not willingly volunteer hand data over to road authorities for enforcement purposes. Especially in LMICs, law enforcement strategies might have a significant safety impact. Therefore, national legislation needs to be prepared to implement such services.

Cooperation models to give access to data

In general, private actors have concerns opening their data to others, mainly based on competition issues. However, to enable success through the automation of parts of the mobility system, cooperation and data exchange between all actors involved – public, private, and individual – is essential.

Therefore, cooperation models need to be prepared, mainly concerning the access to data from private actors. Such cooperation models need to ensure that data supplied for road safety purposes by private actors is not used for commercial purposes by competitors. In addition, it needs to be ensured that the data accessed is used for the specific purpose concerned (e.g. for road safety information) and not for competing commercial services without contributing to the target concerned [41].

Along with the general and legal principles of a cooperation model the technical framework needs also to be prepared. Usually, data formats used and interface descriptions to access data are part of the cooperation model. Ideally such cooperation is set up widely, involving a broad range of actors. This is important to avoid convoluted and potentially contradictory agreements between the individual actors involved.

6.2.2 Legal aspects on data

As discussed above, with regards to access to data, state and national legislation needs to be supportive in enabling data exchange between all actors involved in the automated vehicle domain. In addition to the data access elements, privacy and security issues also need to be considered.

Privacy

Personal information protection is one key principle when dealing with data. The PIARC technical report on “Big Data for Road Network Operations” [21] provides an overview of international examples of personal data regulation. In principle, a “privacy by design” approach needs to be followed when dealing with data and services. This principle needs to be implemented using technical as well as organisational measures. Where personal data (e.g. individual data collected by the vehicle) is concerned, mechanisms need to be in place to anonymise the personal data before forwarding it to any data-processing entity. Also, the privacy principles should be clearly documented and applied within cooperation agreements between different actors

Only if legal legislation allows (e.g. for enforcement issues), can the collection of private data be permitted and the "privacy by design" approach be avoided.

Data protection

Data protection is a core element, when it comes to data exchange and data access with regards to automated vehicles. Two different aspects with respect to data protection need to be considered. Firstly, the data protection within the data holding and data processing entities, which may be public or private entities or an automated vehicle. Secondly the communication link to exchange data between entities needs to be secure.

For a public or private company data protection is a core principle, as discussed in the PIARC technical report on "Big Data for Road Network Operations." [21] When it comes to the protection of data within the automated driving system within the vehicle, it gets more difficult. Holistic concepts for cybersecurity to avoid any manipulations of data that enable or support automated driving functions are still under development.

To ensure secure communication, first it needs to be recognised that only necessary data shall be exchanged between different actors. In addition, for the exchange of this necessary data between different actors, a proper encryption methodology needs to be in place to ensure that each interacting actor can trust the exchanged data. This is necessary as a preventative measure against attacks and misuse of data. Concerning the encryption of the communication link itself, the different strategies are discussed in the PIARC technical report on "Connected Vehicles - Challenges and Opportunities for Road Operators" [21]

6.2.3 Cost of data

Data and service provision by a road network operator based on the marginal cost principle, as discussed earlier, must serve the main interests of the operator - improving safety and efficiency and to reduce the environmental impact of mobility. Accordingly, it should be in the interest of the road network operator to provide relevant data to serve the functions that contribute to positive impacts. Even if a public entity decides to provide data under the open data principle for free, that does not mean that this data has no cost (to the public entity). Taxpayer's or road user's money is usually used to purchase or collect data needed to provide proper services into the automated vehicle.

When it comes to data owned by private entities, where data is part of their daily business, data access is usually based on commercial models, where road network operators might purchase specific datasets. This is the current state of the art situation for traffic management issues as well as traveller information services provided by road network operators. Nevertheless, in an automated mobility system all actors will need to work closely together to deliver the desired benefits with regards to safety, efficiency, and environmental impact. From the road network operators' perspective, the buy-in of data on the marginal cost principle might be an option. But to use taxpayer's money to purchase data from private companies at current market prices can be difficult to justify, along with the complication of the potential inclusion of personal data of individuals. In this regard, current policies of road network operators around the world are highly fragmented and not adapted to the emerging or future issues with big data in in relation to the automated mobility system.

However, as stated in Section 6.2.1, there are currently legislative processes underway that would ease access to in-vehicle-generated data by RNOs. Access to safety relevant data is the starting point with the potential for access to traffic flow data to follow.

When looking at future functions of automated driving systems, even emission data of individual vehicles may be of interest to road network operators. All over the world “low emission zones” are being introduced in cities and other sensitive areas. If an automated car can indicate it can operate with low emissions, it should be permitted to enter “low emission zones”. Future policies might focus on giving physical mobility access to specific areas based on reciprocal access to relevant vehicle or other road user data.

When discussing costs of data, individual user needs are required to be considered. Will a future traveller accept additional costs for data exchange? Most likely not, as travellers have a limited willingness to pay for vehicle connectivity features. However, all actors including vehicle manufacturers and telecom operators will have to look for ways to make services more affordable and attractive to increase the willingness to pay.

6.2.4 Trusted data environments

Regarding access and data protection, the setup of a trusted data environment is crucial. All actors are keen to trust data that is used for supporting automated driving functions. However, trust becomes even more difficult to obtain when more data and service providers are participating. A key aspect for the further development of automated functions within vehicles is how to ensure that data transmitted by vehicles from different brands can be trusted. Similarly, how to ensure that data from different authorities can be trusted – such as, motorway operators, regional road authorities and urban road operators. The set-up of a trusted environment goes far beyond the simple data protection principles discussed in Section 6.2.2 and needs to be based on the cooperation models discussed in Section 6.2.1.

There are two main ways of setting up a trusted environment. Either it can be set up as central infrastructure with a neutral server for data-sharing purposes, or it needs to become a decentralised system, e.g. as cloud-based infrastructure, where access to data is based on common agreements.

When setting up a central server infrastructure, a trusted party will get access to all relevant data via defined interfaces. Based on cooperation models the trusted party will provide access to the data for single actors with required access and privacy controls. This will enable all actors to have access to the agreed data for preparing services for automated in-vehicle functions. Such a model ensures that all data is centrally stored, but the question remains “who is in the position to operate the central data-sharing infrastructure?”

In a decentralised system a central entity needs to curate a catalogue-service providing metadata information of accessible datasets including contractual issues for data access, such as costs of data or appropriate usage of data. The data transfer afterwards is directly between different entities based on the agreed cooperation model. Although the second model looks more complicated, from a commercial perspective it currently looks more promising.

7 IMPACTS ON ROAD NETWORK OPERATIONS (RNO)

7.1 IMPACT OF AUTOMATION ON ROAD NETWORK OPERATIONS

Automated vehicles and various automated functions, associated with human driven and connected vehicles, are currently emerging and are yet to mature or be in widespread use. Although many jurisdictions are making it possible for vehicles with varying levels of automation to use public roads, the number of automated or partially automated vehicles operating on public roads is still very low. Currently, there are no commercially available level 4 or level 5 automated vehicles. Most vehicles with high levels of automation are the subject of trials and pilot projects.

In such low numbers and with technology and automation still in the development and testing phases, the assessment of the impact of automation on Road Network Operations (RNO) cannot currently be measured across most intended applications. Some pilot projects are assessing specific automated functions and are able to indicate some early impacts in very narrow operating contexts. The current expectations of impacts on RNO tend to be largely based on various forms of modelling or prediction. Many predictions over the last decade or more have been publicised that claim wider adoption of vehicle automation will result in significant positive change. More recently it can be observed that prior predictions about large positive changes are being revised in some areas with more tempered, and possibly more realistic, predictions as new research and understanding is developing with increased real-world exposure to complex vehicle interactions.

Within this environment of changing expectations, many RNO are looking to understand their contribution towards supporting and enabling the on-road operation of automated vehicles. Broad impacts are expected on how roads will operate and be operated in an automated future. Adoption of automated vehicles may impact how and where RNO invest in roads and road related infrastructure. Changes in how vehicles interact and how roads are used could impact the existing traffic control systems and tools and how they are used by RNO for both recurrent operating conditions and disrupted conditions.

Two major areas of focus are the likely impact on roadway capacity or congestion and impacts on road safety. A third major area of focus is the changed efficiency of vehicle travel (e.g. reduced fuel costs and other associated operating costs through aspects of platooning and other forms of string formation), especially for certain vehicle classes such as trucks involved in freight transport. Emerging use cases involving automated shuttles and the ongoing shift towards shared mobility and mobility on demand (mobility as a service - MaaS) also have the potential to impact RNO in diverse ways. The potential impact on Road Safety is discussed in more detail in Chapter 9.

7.2 IMPACTS ON TRAFFIC OPERATIONS AND ROAD CAPACITY

One of the key areas of focus and potential benefits from AV on RNO is the increase in capacity of existing road infrastructure.

There are several driver and vehicle interactions which in part determine the amount of traffic that can be serviced, per unit of time. For example, there is a general expectation that Connected and Automated Vehicles (CAV) will be capable of travelling safely with much smaller headways than existing human controlled vehicles. Smaller headways lead to the broad assumptions that more cars, travelling closer together per unit of time, will be able to pass through a section of road, thereby increasing the outflow and theoretically increasing the operational capacity of a road segment.

A second aspect that needs to be considered for any technological impact to be realised is the level of penetration of the technology within the broader vehicle fleet and the available services that drivers wish to subscribe to and utilise. For some automated functions, penetration rates may not need to be high to achieve a reasonable shift in overall outcomes, however, other functions may require quite high or virtually 100% penetration before substantial milestones can be achieved.

The combination of mature and proven automated functions that can truly impact capacity (positively) and minimum penetration thresholds (e.g. greater than 40% for some functions) need to be met before real impacts can be measured on public road networks. In the absence of these two conditions, transport modelling (of varying levels of detail) is currently the primary tool(s) utilised to attempt to understand a wide range of “What-If” scenarios.

Some recent studies have investigated the impact of changed vehicle operations in microsimulation, which enables the individual vehicle interactions to be accounted for in the assessment. Vehicles are modelled with various “driver” behaviour assumptions applied which control how they could interact with other modelled vehicles, simulating the inclusion of automated vehicle functions. Used in combination with reasonable estimates of penetration within the overall vehicle fleet, some useful and enlightening results have been published which consider the potential changes to operational road capacity over time with increased CAV penetration and technology changes.

For example, the Karlsruhe Institute of Technology, Institute for Transport Studies along with the Technical University of Munich in partnership with PTV Group undertook a detailed study, focussing on the impact of automated vehicles on uninterrupted flow on German Autobahns. The work was undertaken on behalf of and with the cooperation of the German Research Association of Automotive Technology (FAT) [42].

The outcomes indicate that rather than there being a significant expected increase in the operating capacity of German autobahns. It was found that the likely outcomes were less optimistic than many previous studies. Of primary impact were factors of slow CAV penetration and restrictions on the ability of automation functions to truly push the limits and take “risks” beyond what human drivers would currently consider.

In the near to medium term (up to 2050), the study indicated operating capacity is expected to decrease. This is due to low penetration rates combined with limitations on automation where automated vehicles would be required to interact in a more conservative manner than human drivers. This more conservative behaviour is due to current limits in sensors, ongoing maturing of communications technologies and systems and to some extent exposure to the risk of developing technology not functioning, not reacting as expected or not as quickly as required.

In the longer term (beyond 2050), modest increases in average operating capacity are forecast, however, significant changes in connected and controlling technologies are required as well as significant levels of penetration of vehicles with level 4 / 5 automation. Even under such scenarios, there is recognition from the study that different types of road segments will be subject to varying levels of operational capacity increases. Extension of the modelling outcomes across the whole autobahn network across Germany in the study suggests that is may be possible to achieve a 30% increase in capacity and therefore a reduction in traffic delays and user costs. It is noted that results derived under a similar approach to modelling traffic in in motorway networks in other countries may show varying outcomes due to the unique nature of motorway segment types and the extent to which they may impact on overall network capacity.

Figure 42 demonstrates the expected capacity changes across different types of motorway segment types. The segment types assessed were basic, merge, diverge and weave sections and are consistent with the segment definitions within the German HBS. It is also acknowledged that in road networks, isolated capacity restraints can restrict traffic from accessing or utilising downstream and upstream portions of the network, either by restricting flow passed a bottleneck or causing congestion and queueing on the approach. Figure 43 demonstrates the expected decrease in capacity on German autobahns with increases in capacity above current day not expected until beyond 2050.

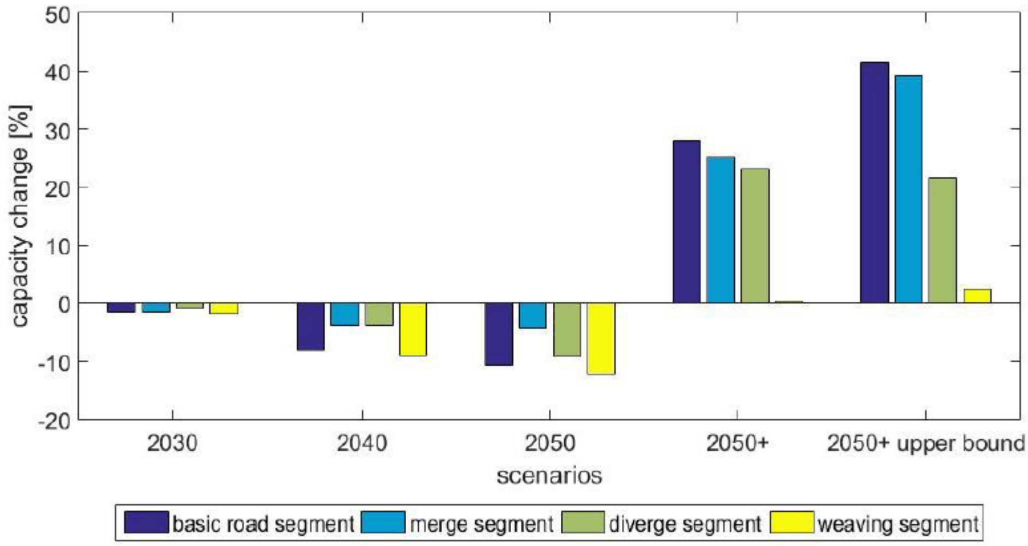

Figure 42: Simulation results representing the percentage change in capacity of each freeway segment relative to the base scenario

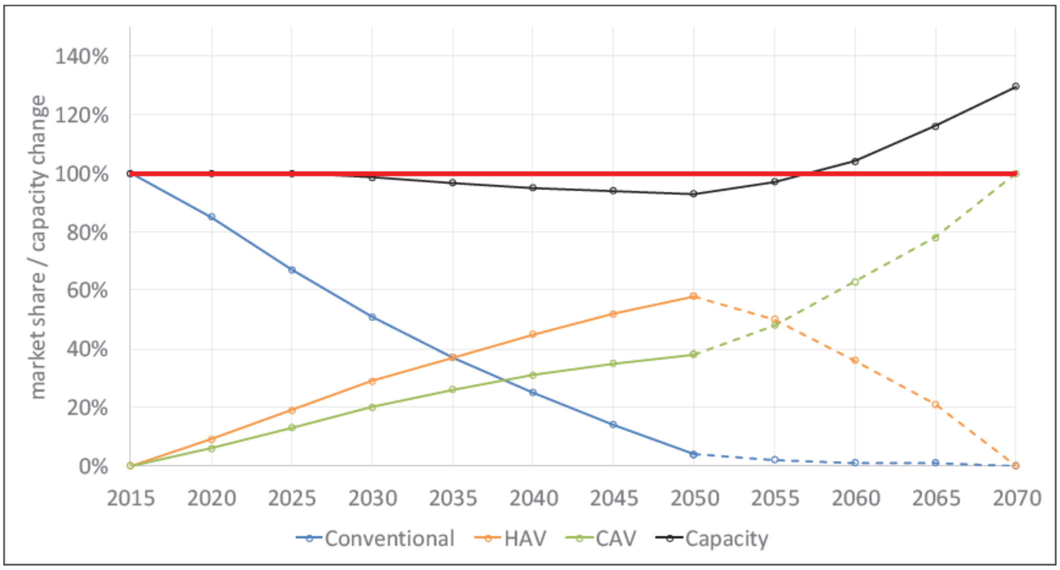

Figure 43: Impacts on AVs on the freeway capacity in Germany

The results from this study may seem conservative, however, they are considered plausible based on the assumptions applied in the analysis. The procedures take into account a mixture of more complex vehicle interactions beyond simply reduced headways. The simulation accounts for lane changing and merging movements which require minimum necessary gaps between vehicles, this imposes a limitation on how small headways can be practically. Significant rates of lane changing have been identified as being necessary for freeways to operate at capacity flows, especially on multi-lane facilities in urbanised areas. Evidence is also emerging that existing vehicle headways in near capacity flows are lower than what has been used for previous capacity assumptions using average headways. Automation of lane changing in highly complex, dynamic and chaotic conditions also requires significant future development to limit disruptive vehicle interactions and ensure safe operations.

The German autobahn study is limited to freeway operating conditions, which is expected to be the part of the road network that is most amenable to early automated vehicle operations. Varying operating conditions on other parts of road networks are likely to result in different impacts on operational capacity. In a similar manner to the freeway environment, care should be taken that a generalised increase in capacity is not necessarily assumed. The many complex interactions that take place on the road network, such as interactions with other road users (pedestrians and cyclists) could make full automation and reliance on automated/semi-automated assistance difficult to implement efficiently and safely.

In addition to freeways, similar assessments and monitoring are required for arterial streets where different interactions take place, especially with a greater variety of different transport modes, including active modes (walking and cycling). Automated vehicles are "defensive" and are programmed to stop or take evasive action when "obstacles" are detected. The arterial street environment presents many more of these potential situations that can trigger such defensive responses and lead to disruptive events and reduced capacity.

The potential for such disruptive events has prompted considerations to segregate or dedicate space (routes) to automated vehicles. If segregation were provided, impacts may still be experienced at transition zones and the disruption may be concentrated near the desired segregation point(s).

Some detailed microsimulation studies of isolated aspects of arterial street operations, such as increased traffic flow through traffic signals during green windows, has been undertaken. Results need to be considered with regard to the variety of interactions that may occur in real world situations which may not have been incorporated into modelling considerations. The impacts of upstream and downstream capacity constraints in the network (at origins and/or destinations) may also impact outcomes and may not be considered in models with limited extents. Interaction with other road user classes tends to be more varied in the real world in comparison to modelling scenarios and is likely to significantly impact arterial street outcomes. Although benefits may emerge for arterial streets over time, they may be reduced compared to ideal operating conditions where greater complexity exists.

RNO need to be realistic about the potential changes in road capacity. While the longer-term impact on capacity may be positive, there is emerging acknowledgement that the road operating environment is likely to go through a transition period where capacity is likely to be reduced at first. Some suggestions have been put forward that road agencies may be able to invest less in expanded road infrastructure over time if operational capacity increases, although increased demand could increase maintenance costs due to accelerated pavement fatigue. However, if the likely scenario is a reduction in operational capacity in the near term, care is needed to ensure adequate physical capacity is maintained and/or appropriate improvements are still considered for the near to medium term. Emerging understanding would indicate that reducing physical capacity in the expectation that CAVs will increase operational capacity would be unwise.

There is currently limited real-world indication of increasing automation inducing further vehicular demands on road networks, due to the limited penetration of automated vehicles. There are expectations that automaton may result in more vehicles circulating on the road network, some with no occupants either returning to an origin or transiting to service an on-demand mobility request. Whether capacity reduces, remains relatively fixed or increases, such increases in on-road demand would inevitably impact road network capacity and operations, especially in urban environments.

7.3 PLATOONING

Platooning is the ability for multiple connected and automated vehicles to travel together at the same speed and with short headways, following each other in a concentrated group or platoon. Connectivity between vehicles is required for platooning to function efficiently and safely. A direct V2V (vehicle-to-vehicle) communications link is considered necessary for platooning to function appropriately. In addition, V2I connectivity may also be desirable to enable monitoring of platooning activities and allow for potential optimisation operations (e.g. activation of signal operations to assist platoon progression).

Several benefits have been identified that platooning operations could deliver:

- Energy savings and reduced fuel consumption through reduction in traffic oscillations and also aerodynamic drag, especially for trucks and heavy goods vehicles,
- Emissions reductions through reduced fuel consumption
- Improved road safety by applying effectively simultaneous braking through V2V communication and reduced speed / traffic oscillations
- Some potential capacity efficiency improvements are considered possible since generally more vehicles could operate closely spaced (increased density).

Over the last three decades, many pilot projects and experiments have been conducted to test and prove the necessary technologies for platooning, being a fusion of many existing automated functions. In some more recent cases, impacts of platooning have been assessed, although on a relatively limited sample.

Measures from the impacts of platooning have primarily been limited to energy savings indicated by reduced fuel consumption. Results from early pilot projects have indicated a 10-17% improvement in these measures, although it was noted that a number of factors may reduce the ability to achieve these benefits, such as interactions with conventional (non-automated) vehicles, road geometry and vehicles configurations. In addition to the efficiency improvements, platooning operations may have the potential to improve road safety and operational capacity, although these are currently difficult or not possible to measure given the limited scope of platooning studies and pilots, and their limited operating environments.

Planning and assessment for platooning operations have highlighted some challenges:

- Length of platoon is bound by V2V speed and reliability to maintain string stability
- Length of platoon must be managed to avoid bottlenecks at highway/freeway entrances and exits
- Theoretically the longer the platoon, the greater the fuel savings, therefore, shorter platoons may limit efficiency benefits
- Practically, long platoons can be disruptive to necessary merging and weaving of non-platoon traffic
- Limitation on the ability for a platoon to change lanes if required and over significant lengths (such as lane reductions on freeways)
- In mixed traffic, cut ins by non-platoon traffic present the biggest challenge to maintaining platooning integrity

The need for limited interruption of platoons and a desire for longer rather than shorter platoons has led to consideration of where best to utilise platooning within the road network. Urban and rural freeways may need to be further investigated. Urban freeways for example typically have close interchange spacing, short trips and high flows, resulting in a greater “turnover” of vehicles in the roadway than on rural freeways. High turnover can impact platooning operations, even if the entering or leaving vehicles are not part of an operating platoon, due to the need to interact with, pass-through or pass-by.

To limit disruption, dedicated lanes could be considered to enhance platooning safety since the behaviour of platooned vehicles would be more predictable and speed would be more consistent; however, understanding the impacts for traffic accessing / leaving dedicated lanes would be necessary. Disruption caused by manoeuvring into and out of “platooning lanes” could also reduce the overall benefits of the platooning operations. Early operations could also result in underutilisation of dedicated lanes where provided, potentially requiring a transition period with under-utilisation of physical road space.

Platooning may not be feasible or appropriate in areas with significant variation in road grade as aggressive speed adjustments may be needed to maintain platoon integrity, reducing the ability to meet desired operating efficiencies. Intelligent monitoring and control systems could account for topography and optimize fuel efficiency while traveling over hilly terrains. Platooning control systems would also need to consider the combined response to unexpected events such as vehicle breakdown, tyre punctures or wildlife strikes.

Platoons of heavy goods vehicles may have impacts on road assets through increased wear and tear on road pavements. Structural implications also need to be assessed and monitored due to closely spaced live loads. Increased resources for monitoring, maintenance and deploying preventative measures will likely put additional loads on road network operators and asset management agencies. Further investigation is also required to determine the need for supporting road infrastructure that needs to be provisioned and maintained by road network operator.

Further assessment is required to identify the use cases for platooning that are able to provide the best outcomes for road users, such as heavy goods vehicles. Platooning functionality may only be possible on a limited number for public roads, such as freeways, and even then, certain conditions may need to pre-exist for reasonable levels of platooning to be considered. Another key aspect is the need for a lead driver (or platoon controller). This may need to be a skill considered essential for platoon formation which poses issues when a platoon controller (and associated vehicle) no longer need or desire to remain with a formed platoon. This may imply that all drivers have minimum skills and training to enable platoon control on as as-needs basis, which a road operator may have some involvement in setting requirements.

Road operators also have a role in influencing and changing regulations that may enable platooning within their jurisdictions. The framework for considering such changes would need to consider both the real benefits that can be achieved as well as the operational risks associated with complex conditions that exist on traffic network. It is noted that some leading truck manufacturers have recently updated their assessment of the economic benefits of platooning which may impact the real benefits that could be expected across logistics fleets.

7.4 AUTOMATED SHUTTLE MUST BE CONSIDERED IN AN URBAN AND RURAL ENVIRONMENT

The deployment of digital technology and new technologies enables outcomes that were previously unachievable. It provides access to new services - carpooling, car sharing, transport on demand, or even bikes and scooters. It promotes the organization of connections between modes and gives very broad access to all mobility services.

7.4.1 Automated public transport systems, an opportunity to develop new services

The rapid development of automated public transport systems positions them as a future component of the public or private transport services offering. Some are marginal yet present in various jurisdictions, particularly in urban areas, and with prospects for further application in peri-urban or rural areas. Although business models may be yet to mature, it is reasonable to consider the prospect of increases in such services in the future. Automated public transport systems have the potential to provide solutions for unsatisfied mobility demands alongside existing public transport services, such as transportation in areas with low density (rural), low flows or demand for first and last kilometre trips.

7.4.2 Services for both urban and rural areas

In rural areas, improving the availability of transportation is key. Rural areas are often very poorly serviced by public transport systems and can struggle to provide adequate public transport for their residents. Continuation of this lack of access to mobility services can increase the risk of isolation of the affected population. Automated public transport systems are a potential solution to address this need, especially for elderly people who are no longer able to drive. In Japan, where more than 25% of the current population are 65 years old or older, several autonomous driving deployment projects initiated by the Japanese government in rural areas are specifically targeted to cater for elderly people. Following field operation tests (FOT) by the Cross-Ministerial Strategic Innovation Promotion Program (SIP), shuttles have been in operation with fares collected by a local NPO since November 2019.

Figure 44:Automated driving of shuttle in rural area (Kamikoani village, Japan)

According to the United Nations [43], in the next 20 years, 60% of the world's population will live in urban cities. This will lead to a large increase in urban travel demand which can be facilitated by automated public transport systems. In many urban cities, reducing the use of individual cars is a key objective. Many cities have adopted such a mode shift (from the use of individual cars to public transportation) as central pillar of their transportation policy. Such a change requires the promotion of alternative transport solutions that encourage drivers to reduce or cease private vehicle utilisation: automated shuttles are seen as one of the key future alternatives.

Foreseen use-cases for public / shared transport by the French Ministry for the Ecological and Inclusive Transition (in charge of Transportation) include:

- Access/egress from stations for the first and last kilometres in sparsely populated areas
- Service in a limited territory, with pre-defined stopping points (e.g. commercial zone, hospital, university, tourist centre)
- Night services on existing lanes by enhancing geographical scope and frequency
- Capacity adaptation (modular platooning) (passenger transportation capacity that adapts to demand by modulating the number of shuttles in platoon mode according to demand)
- Integrated shared mobility + parking services
- Shared mobility on HOVs in peri urban zones

7.5 How RNO can help CAV on work zones/incidents

The sensors onboard automated vehicle are a key component for analysing the road and surrounding operating environment. If onboard sensors are unable to operate effectively, an onboard digital mapping system is needed to supplement the missing information. Road works or incidents may also alter the road layout, changing where the vehicles are expected to travel. The challenge for CAVs is that the scene around an incident may be difficult to interpret. The normal rules of the road may give way to a common-sense approach in which vehicles navigate slowly around unusual obstructions, such as disabled vehicles or debris on the road.

Drivers may be required to interpret manual signals from police officers or other traffic management personnel. Whilst live incident reporting may offer some details of the nature of the incident, the exact configuration of any traffic management measures on the approach to the incident may not be known until the CAV arrives at the incident location and may also be subject to change over time.

A solution to address these challenges is to transfer control of the automated vehicle back to the driver, however this may not be ideal if the driver is not prepared to take control and the situation could deteriorate. Another solution is for the road network operator, through connectivity, to provide I2V services aimed at conveying reliable, accurate, and comprehensive information on Road works (eg: RWW- Road Works Warning – see below) or Incidents to automated vehicles. From a road and traffic operator's perspective, communicating this type of information to CAVs can also improve road worker safety, for whom work zones can be dangerous or even deadly.

Road Works Warning (RWW)

The general concept of this service is to enable a RNO to communicate with drivers through communication from the infrastructure to vehicles (I2V) about road works, restrictions, and changed instructions. The service provides information to approaching vehicles about conditions at a work zone ahead such as the work zone characteristics and activities that could present unsafe conditions. This includes information such as obstructions in the lane or lanes ahead, lane closures, lane shifts and speed reductions. The roadworks site can be fixed or mobile, planned or unplanned. In either case, drivers are warned about the state of impacted lanes and presence of vulnerable workers. Examples of projects using Road Works Warning include SCOOP@F (FR) , US DOT data exchange project (USA), Eco-AT project (AUS - GE –NL), C-ITS Pilot Project (South Korea)

Regarding immediate response/emergency situations, a "CAV Compliant First Respondent's Procedure" could be developed. Such a procedure outlines a series of steps that the first authority on scene should follow. A suitable early step may be to set-up warning signs / signals / mobile roadside units (RSU) which alerts nearby CAVs that the area is in an unusual state and that it should either be avoided or navigated carefully. Signs / signals for this purpose should be easily identifiable by CAVs. Close corporation with organisations developing CAV technology would be required in developing such procedures. Report Summary - Transport Systems Catapult – 2017

7.6 Traffic Management by RNO

As discussed earlier, sensors onboard automated vehicles analyse the road and surrounding operating environment. If the analysis is insufficient, an onboard digital mapping system is needed that can supplement the missing information. Generally, an automated vehicle's ability to perceive its environment is based on data fused from embedded sensors, GNSS/mapping navigation and V2X.

The information about the surrounding physical infrastructure will therefore become increasingly digital. The challenge then is to build this digital infrastructure and to keep it up to date as conditions change. CAVs require up to date information to enable the selection of the best route, and also ensure that they position themselves appropriately and safely in the roadway. This information needs to include roadworks, road closures and diversions, including detail about the location, dates of disruption and scale of disruption. This digital infrastructure also raises the issue of data exchange standards and formats.

In Australia, Austroads published a Connected and Automated Vehicles (CAV) Open Data Recommendations report on 23 August 2018 [24]. According to this report, there is a need for a consistent messaging framework that would allow RNOs to query the required data from vehicles. RNO data types that were identified to be a high priority for CAVs include:

a. Live feeds from traffic management systems for variable speed limits and lane closures
b. Live feeds of traffic signal phase and timing data (such as SPaT messaging)
c. Available data for emergency road closures (fire, flood, etc)
d. Available data for temporary conditions associated with works, events, and incidents
e. Advance notification of new and changed roads (that may not have been mapped)
f. Coordinate with actions already occurring on speed limit data and extend to cover other traffic restrictions (vehicle size and mass)

Changes to business processes may be required for RNO to supply the most suitable data to CAVs. An example is the need for RNO to be able to supply the most relevant and useful data about roadworks, events and incidents on the main road networks, which may require a higher level of accuracy and timeliness suitable for the ODD which may not have been the case in a non-CAV scenario.

8 RESPONSIBILITY AND FINANCING

8.1 Responsibility and insurance

There are a number of challenges and unknowns with regard the responsibilities and obligations of the various actors involved in CAV deployment and operations, including:

- Responsibilities and obligations of drivers and owners: who or what determines whether the driver of an automated vehicle must be vigilant? Are existing rules of civil liability sufficiently clear for insurance companies?
- Responsibilities and obligations of car manufacturers: under what conditions can a car manufacturer test and market its vehicles? Are any extant deviations from existing rules of penal and civil responsibility demonstrably justifiable?
- Responsibilities and obligations of RNO: what should they provide and to what level of service? What happens if that level of service is not granted?

The following sections provide some aspects for RNO to consider.

8.1.1 Insurance and responsibility of the driver

In France, since 1985, there is a law ensuring a fast-financial compensation for victims of car crashes ("Badinter" law). The victim can claim compensation from the driver or, if he/she is not identified, to the owner of the vehicle, who has an obligation to have an insurance covering civil responsibility. Therefore, from a civil responsibility point of view, the case of an automated vehicle does not change anything. Insurance of the owner, if not the driver, will provide compensation to the victims.

Insurance costs of an automated car are as uncertain as the road safety benefits. It is probable that the first automated cars will have higher insurance costs due to some recent accidents in the USA involving automated operations, although this would be expected to decrease once liability of the system is widely admitted.

Penal responsibility, however, will depend on the instructions given to the driver, and will still be upon the driver for lower SAE levels, if the driver is supposed to remain alert to the road conditions and to react when required.

8.1.2 Responsibility of the car manufacturer or of the car

If an accident occurs when the automated mode is active and the vehicle has not asked the driver to regain control, the responsibility may apply to the car manufacturer. This responsibility would be linked to the homologation of the vehicle and its conformance with the homologation framework.

This framework will probably include the ability to update, as systems that are introduced in the next few years are unlikely to be perfect nor remain in place for extended periods. As versions become outdated, it is likely that many earlier conforming vehicles will still be operating on the road. A key goal should be to limit the physical risk of these systems through a variety of technical and contractual tools to enable monitoring, over-the-air updates, and even virtual recalls as necessary.

Some lawyers consider that automated cars and more generally robots should be considered legal entities, and that a new brand of laws should be dedicated to them, building upon the "3 laws of robotics" of the science-fiction writer I. Asimov:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey orders given by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence if such protection does not conflict with the First or Second Law.

8.1.3 Responsibility of the RNO

In France, the responsibility of the RNO is to perform "normal maintenance". If this is not the case, the RNO may be considered to have a responsibility if an accident occurs.

The question is how the concept of "normal maintenance" will evolve with automated cars. It is reasonable to expect that a minimum level of service is defined for the contrast of road markings to support CAV operations for example. However, it is technically impossible to predict or detect the exact time when the contrast will fall below a given intervention threshold and to then enact remediation instantaneously. Such deterioration below a threshold is a random outcome related to the number of wheels having crossed the line, the weather conditions over time and the quality of the asset when provided. This implies that vehicles will always need to cope with situations with damaged markings (potentially with the assistance of a reconstructing pavement marking algorithm or information from a HD map) and that "normal maintenance" may rather be defined by a frequency of surveillance of the markings. A similar approach needs to apply to connectivity, which cannot be guaranteed to work 100% of the time. This tends to be well integrated by car manufacturers to date, with connectivity considered as an additional sensor, thereby providing redundancy and including fallback solutions based on the vehicle's optical and other sensors, HD maps and consideration of the ODD.

Some innovative automation use cases rely on the infrastructure to provide a part of the artificial intelligence (enhanced perception through sensors on the infrastructure, guidance through waypoints in roadworks zones, or even supervision of specific fleets such as public transport or platoons). This implies more responsibility by the road operator and/or the road equipment provider to both deploy the additional supporting physical and digital infrastructure and provide the information to CAVs.

8.2 Costs, benefits and financing

8.2.1 Benefits expected

In general, most of the research today, indicates uncertainty about the possible system effects of the ongoing technical and digital development on the road transport system. From a business perspective however, it is clearer that automation, electrification, and digitization in the short and medium term will result in significant benefits. When it comes to travellers, the picture is more fragmented, as their choices are not only governed by economic rationality, but also by individual values, lifestyles, and acceptance of new services.

The development of the new technology, regardless of traffic type, has the potential to improve the accessibility to the road transport system, capacity utilization, increased traffic safety, and reduced climate emissions. These benefits, however require well thought out implementation of the new services and functions in societies with minimum negative side effects (such as; pricing, cyber security, counteraction of digital segregations, etc.), and sufficient incentives that promote behavioural changes (circular and shared economy).

8.2.2 Estimation of costs

It is quite difficult to advise on the investments needed for digital transformation of road transport systems as the size of the gap between the investor communities and the digital industry varies heavily from one country to another. The challenge for the public sector in this context is its low investment commitments despite the recognition of the importance of the digital transformation for developing a safer and efficient road transport system. However, the gap between the current status and the desired digitalization needs to be studied, required investments estimated and carefully planned and funding institutions (both private and public) identified in order to implement effective of measures to drive the development forward. The plan needs to also take digital integration into consideration as most capital investments today tend to be focused on urban areas. Developing initiatives and financing solutions for the digitalization projects in rural areas is an important aspect in this context.

A recent study estimates the cost of the investment needed in IT communication infrastructure to enable large scale deployment of V2I as EUR5 - 8bn in the EU and US$7-12bn in the US. This study was conducted by Ricardo Energy & Environment on behalf of 5G Automotive Association and submitted in August 2020 [44]. For the achievement of this scale of investment the report urges broad cooperation between cities, road operators and mobile network operators.

9 SOCIAL ISSUES AND THE CONSIDERATION OF HUMAN FACTORS

9.1 MAIN PRINCIPAL QUESTIONS FROM THE PERSPECTIVE OF SOCIETY

9.1.1 Motivation for seeking automation

At the outset, a fundamental question that is rarely fully articulated but should be asked is "why automate in the first place?" [45] According to [46] there are a range of potential motivations for seeking to automate human functions including:

- When it is dangerous for humans to carry out a task (e.g. driving impaired).
- When it is impossible for humans to carry out a task (e.g. accurate night-time sensing or sensing beyond line of sight).
- When carrying out a task is difficult for humans (e.g. rapidly reacting to sudden obstacles).
- Just for the sake of automation (e.g. as a way of creating a market even if no safety benefit is conferred to users).

The current development of automated driving systems is motivated by all of these in different measure.

Perhaps a more safety-relevant way of addressing the issue of what motivates automation centres around the two questions, "What tasks can automated systems do better than humans (from a safety perspective)" and "what tasks can humans perform better than automated systems?" These are central questions that have accompanied many past technology developments and articulated by Fitts [47] in reference to machines in general within in a framework that has remained surprisingly relevant today, even in the context of vehicle automation and technologies that were barely imaginable at the time [48], [49].

9.1.2 Potential safety benefits

Foremost among the predicted benefits of increased and complete vehicle automation is the promise of improved safety. With few exceptions [50], [45] this predicted benefit is accepted uncritically based on the observed rate of human error-involved crashes. Claims of a more than 90% reductions in road traffic deaths resulting from automation eliminating crashes linked to human error are untested. It seems likely that the number of road casualties will decrease with automation, but crashes will not disappear. In certain circumstances, more crashes may occur among "average" drivers that are not prone to risky behaviour. This is particularly likely in circumstances where drivers are required to take over from automated driving in emergency situations.

Much of the focus on the potential safety benefits of automated driving has been centred on the elimination of human error in the driving task. That is because humans make mistakes in judgement, may drive impaired or distracted, may simply not be adequately aware of the driving environment or may not react quick enough to rapid or unexpected changes. The Safe System approach inherently recognizes the capabilities and limitations of humans when designing and operating road transport systems.

Errors arising from interaction with the traffic and road environment can be limited by understanding these interactions and designing the road transport system from these interactions, in order to guide the road user to behave in a way that is as safe as possible. Yet, as human error cannot be fully eradicated there is a need, at the same time, to mitigate the consequences of mistakes. In simple terms, this basic principle of a Safe System starts with the insight that human error should no longer be the primary cause of crashes. Instead, road crashes are a consequence of latent failures created by decisions and actions within the broader organisational, social, or political system which establishes the context in which road users act.

The lack of experience and data complicates an assessment of how safe automated driving really is. It is further complicated by the lack of a common framework for such a safety performance assessment and by rapid changes in its object; a self-driving car is a combined hardware and software system whose critical performance characteristics can change radically with a software upgrade.

Vehicle automation strategies that keep humans involved in the driving task seem risky. A shared responsibility for driving among both automated systems and humans may render decision making more complex rather than simpler. Therefore, the risk of unintended consequences that would make driving less safe, not more, could increase.

Humans retain an advantage over single sensor-based automated systems in many contexts. Overcoming this gap requires combining input from several sensors. In some cases, safe operation will require vehicles to communicate with each other and with infrastructure beyond the line of sight. However, relying on this connectivity for safety performance involves risks, especially regarding cybersecurity. Whether vehicle automation should move from a reactive safety paradigm (where vehicles rely on their own capabilities) to a proactive safety framework (where vehicles are embedded in a communicative network) is still debated. Potential uses vary in different countries according to GDP, population density, technology advancements, etc.

9.2 The limitation of potential benefits of AV by a range of human factors

It is possible that the potential safety benefits of C-ITS and AVs may be undermined by a range of human factors if not properly addressed. C-ITS and automation will change the driving task, either by providing additional sources of information or by automating some, to all aspects of the driving task. This can lead to changes in driver behaviour, some of which may be unintended by the system designers. In road safety, the term ‘behavioural adaptation’ (see e.g. [51]) is typically used to refer to the unexpected or unintended behavioural changes that appear in response to the introduction of a change in the vehicle or road environment, that may influence the predicted safety benefits of this change. The anticipated behavioural adaptation factors leading to changes in driver behaviour are not always anticipated by vehicle and system designers. Some of the human factors included:

- Technology over-reliance, causing issues when drivers are required to regain vehicle control or use a non-equipped vehicle.
- Driver overload (from system status monitoring), or underload or loss of vigilance potentially leading to reduced situational awareness and difficulties coping with sudden demand increases, such as during resumption of manual control. Issues with loss of vigilance and situation awareness may be particularly apparent with SAE Level 3 or ‘conditional automation’.
- Driver distraction when startled by alerts, having their attention drawn away from critical information or when engaging in distracting activities while in charge of an automated vehicle.

- Drivers failing to trust and/or accept the technology, leading to system misuse or disuse.
- Loss of driver skill, leading to problems in the event of automation failure and resumption of manual control.

9.3 New human factors can arise

9.3.1 Driver Overreliance (Automation Complacency)

Over-reliance, also called ‘automation complacency’ [52] or ‘delegation of responsibility’ is an important human factor when introducing C-ITS and automation. Over-reliance occurs when drivers delegate full responsibility of driving tasks to the system (regardless of whether the system is intended to assume full responsibility or not), or delegate responsibility for other driving tasks that the system was not designed to address. Over-reliance can occur because of a loss of vigilance or drivers misunderstanding the functionality and limitations of the technology. This creates problems when the system is no longer active, such as when drivers use a non-equipped vehicle or when drivers are required to regain vehicle control. Over-reliance has been observed in several Intelligent Speed Assistance (ISA) studies, where drivers, forget to change speed upon entering a different speed zone when the ISA is no longer active [53]; [54]. Numerous instances of over-reliance on Adaptive Cruise Control (ACC) systems have also been reported. For instance, drivers were observed to brake later in response to a braking lead vehicle when using ACC [55]; [56] and some drivers failed to reclaim vehicle control and collided with a lead vehicle when the ACC failed without warning [57]. However, drivers can effectively assume control from ACC in critical braking situations if provided with a warning [58].

Educating drivers about the capabilities and limitations of C-ITS and AV technologies and providing timely warnings when the system moves outside of its performance envelope can help reduce the risk of overreliance.

9.3.2 Adoption of Risky Driving Behaviours

If C-ITS and AV technology are perceived as providing safety benefits, they can change drivers’ perception of driving risk and encourage risky driving behaviour. Drivers may adopt risky driving styles to adjust their level of preferred risk, to experiment with the system, or to improve their mobility and compensate for factors such as lost time, due to lower speeds created by some systems. When using ISA, for example, drivers compensated for slower overall speeds by driving faster on roads where ISA was not active, or in situations that warranted lower speed, such as when turning or in poor weather [53]; [54]. The period of mixed traffic, where automated vehicles will share the road with non-automated vehicles, may also present issues in terms of the behaviour of drivers of non-automated vehicles. Issues may occur for example, if drivers of non-automated vehicles expect automated vehicles to behave in the same (suboptimal) manner as non-automated vehicles and this expectation is not met [59]. A preliminary analysis of the crash rates of automated vehicles, [50] found that although automated vehicles had an almost five times higher crash rate than conventional vehicles, none of the crashes were the fault of the automated vehicles. Such findings suggest that the drivers of conventional vehicles may have uncertainty or difficulty reconciling how they would expect automated vehicles to behave. Alternatively, drivers of non-automated vehicles may adopt similar behaviours to automated vehicle platoons which are incompatible with safe manual driving. For example, in a simulator study [60], participants driving non-automated vehicles were observed to adopt similar following behaviour to automated vehicle platoons, by driving at a reduced headway to lead vehicles.

9.3.3 Loss of Skills

Automating parts of the driving task may lead to a loss of skill and this problem is likely to increase as the level of automated driving increases [61]. If humans do not perform a task for a period, they begin to lose the skill to perform that task effectively, even if they were able to perform it to a high standard previously. Loss of skill can lead to problems in the event of automation failure where the driver is required to regain manual control. This requires a skilled driver who needs to perform the manual control tasks, as well as the automation, which often occurs under time pressure. A challenge for system developers, manufacturers and governments will be designing automation and implementing policies, to ensure that drivers can maintain a minimum level of driving skill (i.e. by requiring intermittent manual control) or removing the need for drivers to intervene at all in the driving task.

9.3.4 Other issues

Driver Workload

An attempt to reduce workload through driver support systems can potentially increase driver mental workload, as these systems add information which must be monitored by the drivers. Humans are poor at monitoring tasks [62] and research has shown that monitoring systems is stressful and can cause high levels of workload [63]; [64].

Driver Distraction

Automated systems can be a distraction risk, if they startle the driver with alerts, if they present confusing, excessive, or false alerts, or they divert the driver's attention away from safety-critical events. We can also expect that there will be limited common standards for warnings and alerts among different competing car manufacturers.

Driver Acceptance & Trust

Acceptance of AVs by drivers is a critical factor influencing the successful uptake of these technologies and their effectiveness in improving road safety. A failure of drivers to accept a technology can lead to them not using the system in the manner intended or failing to use it at all. Acceptance is closely linked to driver trust – if drivers do not trust that a system is reliable, safe, secure, and effective, then they are unlikely to find it acceptable. But reality shows that people accept new technology more than it appears in attitudes surveys.

Regaining Manual Control

A whole host of factors including loss of skill, loss of situation awareness and overreliance can cause issues with drivers regaining control of an automated vehicle. Reduced situation awareness, for example, has been associated with a delay in appropriate braking when a failure in ACC was encountered [65], [66]. Some research show that partial AVs will worsen distracted driving, by lulling drivers into complacency. Tests at Virginia Tech found drivers took an average of 17 seconds to respond to takeover requests from Level 3 AVs.

HMI Issues

As more systems are introduced into vehicles, integration, particularly of aftermarket systems, will become increasingly important, as drivers will need to be able to distinguish between information from multiple systems, and the systems will need to communicate with each other to ensure that any alerts or information provided are prioritised so as to not overload and confuse the driver with multiple sources of information at once [67].

9.3.5 Examples of 11 new social issues and challenges that will arise

Challenge 1: Today, the work of industry and the discussions with national and EU stakeholders (governments and their agencies) concentrate on research, testing and type approval. First activities which are focussing on the development of traffic rules have started in some countries. What is the total scope of affected policy and regulation?

Challenge 2: On type approval regulation: Level 2 is still under strong discussion, Level 3 has not really started yet, and as for Level 4 and 5 there is no clear view on how to proceed. How can the type-approval approach evolve? How to set up the regulation in a timely manner to ensure that it is in place when the technology is ready? How to develop regulation and technology in parallel, in a harmonised way, without creating a chicken-and-egg dilemma? How to deal with software updates?

Challenge 3: How and to what extent would it be required to adapt and harmonize traffic rules for a quick introduction of higher automation levels?

Challenge 4: What liability framework needs to be in place to facilitate market penetration from a legal/liability perspective?

Challenge 5: AVs will potentially grow total vehicle miles travelled (VMT) by 14% [68]. What policies should be taken to motivate people to reduce car use or to share? To what extent should governments limit freedom of travel? What kind of new traffic pricing policies should be taken?

Challenge 6: The transition period when roads will be shared by both conventional and automated vehicles will probably be very challenging. It is unclear whether roads would be safer or more dangerous during this transition period. Increased risk during the transition period is, in part, due to the likelihood of drivers becoming over-reliant on technology and taking risks they might otherwise avoid. Some drivers may simply opt to turn off new safety features. How can we influence people to comply with new safety features?

Challenge 7: Equity – One of the main questions is the role of AVs and CVs in fostering social inclusion. A socially inclusive society is one that provides all people and communities with the opportunity to participate fully in political, cultural, civic, and economic life. Research suggests that inclusive societies foster greater social cohesiveness and better standards of health, while social exclusion and lack of community interaction are associated with poorer health outcomes and earlier death. Social exclusion affects a wide range of individuals and communities, although certain groups, including seniors and persons with work-limiting disabilities, are at particular risk. While many factors contribute to social exclusion, inadequate transportation has been identified as a key contributory cause. This is because an inability to access or use personal or public transport can leave people unable to access health services, employment opportunities and social activities. The problem can be particularly acute in rural areas.

The issue of equity was raised for example by Mr. Litman. Although he felt that AVs were “very unlikely” to reduce traffic congestion on city streets in the foreseeable future, he explained that dedicated AV lanes could be implemented with the intent to reduce congestion on highways. Nonetheless, he cautioned that publicly funded AV lanes could raise questions of social equity, as only those who can afford to buy or use AVs would benefit from them (as noted earlier, AVs are initially expected to be relatively expensive). This could be especially prevalent in LMICs.

The equity issues also include changes access to mobility. For example new traffic pricing policies can lead to time segregation (less wealthy part of society will travel only in times when they can afford to pay) and inequality in access to mobility (e.g. geofencing for less advanced vehicles) – a form of geographical segregation.

Challenge 8: Loss of tax revenue. Nowadays vehicles are driven by people who are subject to paying tax through the income earned partially or wholly through a driving task. When machines will drive without professional drivers, governments will lose part of the tax revenue and will be forced to tax “machine work”. This could lead to a scenario in which human drivers will be cheaper to hire regardless of technological development.

Challenge 9: Privacy issues. With more intelligent and assistant systems in automated cars, more data will be gathered from drivers and passengers. This is associated with two main risks. 1) The data are vulnerable to abuse and could be the target of cyber-attacks. 2) The data will be source of commercial gain for their owners but the original “providers” – road users – will have little to no gains from the monetization of their data.

Challenge 10: Health issues. The use of AVs is expected to have impacts on the lifestyle of its users. For example, alcohol and drugs consumption could rise significantly. As the necessity to drive is one reason that discourages drivers from drinking excessively, it is expected that alcohol consumption will rise by 10% when “drivers” become “passengers” of driverless vehicles.

Physical health is not the only subject of concern. Driving a car is a human activity where people experience strong performance situations and solve complex tasks under stressful conditions. Removing manual driving can thus lead to attempts to shift this gaining of experience into other life domains which could become riskier. Another consequence is degeneration of human performance skills.

Challenge 11: Resistance to change due to fear of job losses in LMICs – For example, in South Africa more than 51% of households rely of the mini-bus taxi industry as their form of transport. The mini-bus taxi owners, and their employed drivers, will resist the change to move toward automation. In a country with an unemployment rate of 29% (six times the estimated average global rate), the general workforce (including taxi drivers) is likely to resist automation at all costs. In fact, many industries, such as the construction industry are encouraged by government to use fewer machines and to rather use labour intensive techniques to increase job opportunities.

9.4 RECOMMENDATIONS FROM THE PERSPECTIVE OF SOCIETY

For governments:

- Reinforce the Safe System approach to ensure automated vehicles are used safely.
- Apply Vision Zero thinking to automated driving.
- Avoid safety performance being used as a marketing parameter to differentiate competing automated vehicles.
- Carefully assess the safety impacts of systems that share driving tasks between humans and machines.
- Require reporting of safety-relevant data from automated vehicles.
- Develop and use a staged testing regime for automated vehicles.
- Establish comprehensive cybersecurity principles for automated driving.
- Ensure the functional isolation of safety-critical systems and that connectivity does not compromise cybersecurity or safety.
- Provide clear and targeted messaging of vehicle capabilities.

For legislation:

Proactive policy, including specific rules, can provide companies the legal clarity they need to make investment and deployment decisions and can enable governments to appropriately handle automation technologies at each of the regulatory gates described above. Nonetheless, prematurely codifying requirements can freeze unrealistically high or low expectations into the law in a way that ultimately causes that law to lag rather than to lead. Duplicate, or repeat efforts to develop rules can force developers to invest resources in lengthy legislative debates and regulatory processes.

For these reasons, informal dialogue may often be preferable to specific rules. Importantly, countries and regions with a specific "automated driving law" are not necessarily ahead of those without one. The US state of Michigan, for example, recently enacted a law that explicitly prohibits the operation of automated vehicles for any purpose other than research and development testing.

As for the uniformity or flexibility of legislation there is no clear answer. Uniform regulation across multiple jurisdictions can reduce the cost and complexity for developers of systems that will cross national or subnational borders. Designing for one set of rules and roads is daunting enough; designing for dozens only amplifies this challenge. Flexible regulation, however, might more easily accommodate existing regional differences, local start-ups, and unique demonstration projects.

The choice between ex-ante regulation (particularly regulatory standards) and ex-post regulation (particularly recalls and civil suits) implicates flexibility. Forward-looking rules provide more certainty but less flexibility; backward-looking measures provide more flexibility but less certainty. These trade-offs are particularly relevant to concerns raised about the liability of automated vehicle manufacturers and associated companies for injuries related to their products. These concerns, however, likely derive at least as much from technical uncertainty (how will these eventual products perform) as from legal uncertainty (how will courts determine liability).

For research funding:

More democratic research is needed in AVs. The main expected target groups (people from remote areas, women, seniors, etc.) are usually not adequately part of designing and testing of AVs which results in lower trust and acceptance in these groups and leads to some unintended consequences (e.g. higher collision rates involving people with darker complexion as sensors are less adapted to applicable ethnic groups).

There is also question of public money invested in research and development of AVs and infrastructure for them. Society should express whether it is worth the money and effort or whether that money should be invested in enhancing existing and well adapted technologies and safety features (e.g. scenario of manual driving with ADAS).

The third main area from a social perspective is cultural research. There is wide range of issues that can be solved by technical solutions which are mainly connected with the impacts on individuals' abilities as a result of using AVs – loss of skills, handover, distraction, etc. These solutions can be implemented worldwide with minimal need for adaptations (as it is mainly derived from biological limits). But in the case of more general issues like ethics or policy making, each country will need to do its own research to consider localised and potentially neighbouring contexts. Minimal ethical principles must be set, but ethical principles are not the same around the world.

10 CONCLUSION

Vehicle Automation – at least SAE levels 3, 4 and 5 – is still in a testing phase in most countries of the world. Many tests at level 3 have been performed successfully on open roads without any changes to the road infrastructure and without any impact on congestion. However, in many situations, drivers must still take over control of the vehicle – a fall-back solution that is still allowed at level 3, but not at level 4 or 5.

To reach the higher levels of automation, some support from the infrastructure is expected to be needed. In particular, well-maintained lane markings and the provision of landmarks seem to be key. But automated vehicles cannot rely solely on physical infrastructure, which has limits. For example, it is not technically possible to predict the time of degradation of lane markings below a level where it can impact automated operations. Therefore, digital infrastructure, including data provided through high-definition maps and/or through vehicle-to-infrastructure connectivity, must be made available. First insights on this digital infrastructure have been outlined and discussed in this report.

Regarding the impact on congestion, some models show that it should be slightly negative at low penetration rates and grow positive (increase of capacity) only by 2050 or 2055.

Some studies also show that the impact on road safety should be positive at high penetration rates, as already observed on ADAS systems, but this supposes that many human factors are considered, such as driver overreliance or loss of driving skills. The report mentions 11 key challenges to tackle regarding social issues to make automation a success.

11 RECOMMENDATIONS

11.1 RECOMMENDATIONS FOR DECISIONS MAKERS

As in any type of business, it is important to have a user centric perspective. General digitization of the road transport system and the introduction of highly automated vehicles needs to be undertaken in a context that improves the everyday lives for individual and business users and with the aim of improving safety and accessibility in a sustainable society. The focus needs to recognise that the benefits and efficiency for individual and businesses are achieved through the collective contribution by all actors involves. To create a balance between the possibilities and risks of digitalization, functional safety needs to be the primary driver from the outset. Therefore, the changing transport system needs to be tested to ensure it can fulfil the requirements of functional safety across the challenges associated with conflicting technologies, societal conditions and human behaviours.

Wide introduction of automated vehicles, however, requires collaboration where different competencies and actors identify challenges and opportunities together. Opportunities will include, but are not limited to, business models, law and security, technical development, standardization, and information management.

It has been apparent through history, and it will be true for vehicle automation, that new technology helps to develop new solutions for improved mobility and push forward the road transport system towards sustainable goals. Such solutions can often be more effective than the prior or more traditional measures they will replace. Therefore, funds (both public and private) need to be reprioritised and allocated to enable the introduction of solutions based on new technology where sound evidence and due consideration demonstrate that the benefits are worth pursuing for the overall benefits to communities and society more broadly.

The following are the most important recommendations for road authorities and operators:

<u>Learn by doing</u>

Road operators and road authorities should monitor AV testing and seek feedback from OEMs concerning any difficulties experienced due to infrastructure – both physical and digital. A staged testing regime for automated vehicles should be developed, involving all relevant stakeholders.

<u>Build the digital infrastructure to complement and complete the physical infrastructure “picture”</u>

Automated vehicles cannot rely solely on physical infrastructure, which has inherent limits. For example, the deterioration of lane markings or impacts of weather events and natural phenomena on infrastructure cannot always be known or remedied in a fashion that always provides certainty for automated vehicle operations. Digital infrastructure, such as a digital environment through connectivity and/or HD maps, will be key to allow vehicles to have sufficient clarity where sensor information is incomplete.

<u>Access to data and need for standardization</u>

It is very important that authorities take responsibility for controlling and coordinating public basic data within the road transport system, in accordance with the intentions of the basic data collection and use.

IT and communication infrastructure

Investments in IT and communication infrastructure are needed to enable connectivity throughout the road transport system. This requires coordination of public and private investment to meet the road transport challenges and deliver policies more effectively.

Legal aspects

Authorities need to review and present sets of new legal frameworks and commercial preconditions for large scale introduction of automated vehicles as well as facilitate the exchange of public and private data, both at national and international levels.

Balance between opportunities and risks

Authorities need to create conditions for continuously developing knowledge and methods for assessing threats and balancing cyber security, especially considering the criticality and required functionality of the road transport system.

Collaboration and collaboration areas

Frameworks that contain principles and recommendations need to be developed through collaboration between the various public and private actors. Authorities should take the lead and conduct relevant activities together with commercial actors and users with the objectives of developing the next generation road transportation.

Steering mechanism

Automated vehicles will likely create new opportunities to contribute to the goals of a sustainable road transport system. To avoid negative system effects and to obtain the desired changes, policy instruments may need to be developed for funding both the transition and planned ultimate scenarios (e.g. taxes, fees, and other regulations).

Financing of digital transformation for the road transport system

Further development of cost-benefit analysis needs to be undertaken in order to estimate or better describe the possible and likely societal benefits and associated costs in order to asses and prioritize various investments on various components, in particular communications infrastructure, road pavement marking, digital twins, HD Maps etc.

Take account of social issues

- Reinforce the Safe System approach to ensure automated vehicles are used safely.
- Apply Vision Zero thinking to automated driving.
- Avoid safety performance being used to market competing automated vehicles.
- Carefully assess the safety impacts of systems that share driving tasks between humans and machines.
- Require reporting of safety-relevant data from automated vehicles.
- Establish comprehensive cybersecurity principles for automated driving.
- Ensure the functional isolation of safety-critical systems and that connectivity does not compromise cybersecurity or safety.
- Provide clear and targeted messaging of vehicle capabilities.

11.2 Recommendations for road operators and road authorities

11.2.1 Short term

- Follow tests and obtain feedback from OEMs about any difficulties associated with the infrastructure
- Require reporting of safety-relevant data from automated vehicles
- Ensure a proper level of maintenance of lane markings and critical physical road infrastructure to support vehicle positioning and guidance.
- Test and develop infrastructure support through I2V connectivity in some critical zones (e.g. road works)
- Ensure the functional isolation of safety-critical systems and that connectivity does not compromise cybersecurity or safety.

11.2.2 Mid-and long term

- Adapt road design rules and maintenance strategies that respond to lessons learnt
- The physical infrastructure will become increasingly digitised. A significant challenge is to build this digital infrastructure and to keep it up to date (in particular HD maps)
- Support harmonization of traffic signs and markings
- Automated shuttles need to be considered in an urban and rural environment

11.3 Recommendations for LMICs

Many of the changes being brought on by the technological advancements in mobility, will prove to be very disruptive and potentially have a negative social and socio-economic impact in LMICs in particular. As discussed in Chapter 9 (Social Issues and the Consideration of Human Factors), many LMICs have extremely high unemployment rates (29% - In the case of South Africa, which is six times the global average), and the retention and creation of jobs is a priority for the their governments. Therefore, any form of automation will be a threat to humans, in terms of job losses and resulting livelihood. However, LMICs cannot afford to get left behind the global community. It is the responsibility not only of governments but the transport industry at large to prepare for these changes and to not be caught off-guard.

There are many automotive industry producers in LMICs (Africa, Asia and South America) and they export most of the vehicles they produce to some of the more developed countries (e.g. 60% in the case of South Africa). Due to the technological advancements in the global automotive industry, export markets across the world are all at various stages of testing and deploying CAVs. These LMIC automotive producers will be expected to meet the demands of the export market in the production of these vehicles. It is therefore imperative that LMICs prepare well in advance to be ready to meet the increasing demand for new technologies and automation.

Irresponsible behaviour and human factors account for up to 90% of serious accidents in South Africa, it is therefore essential that the benefits of technology in the form of CAV are explored to remove the human element as far as practicable. There are many socio-economic challenges that need to be addressed first, but the benefits of CAV technology cannot be ignored. If the LMICs are to strive for “vision zero,” in line with many developed countries, the benefits of CAV technology need to be fast-tracked by governments, road authorities and the transport industry.

It is therefore recommended that LMICs:

- Start small, with pilot deployments on the most mature services as piloted in the developed countries
- Start with safety services first as road safety is the biggest motivation for deployment
- Explore the law enforcement possibilities of CAV and C-ITS to assist in improved road user behaviour.

11.4 RECOMMENDATIONS FOR PIARC

Automation will continue to be a hot topic in the next decade for the road transport and mobility community. It is recommended that work is continued, with a new Task Force, until next World Road Congress in 2023.

A few topics to be considered in greater depth are, among others:

- Cost/Benefit analysis and financing models
- Necessities and Luxuries - “must haves” and “nice to haves” from the perspective of society
- Universal aspects should be discouraged or prohibited from being used for competitive marketing of vehicles and features
- Minimal ethical principles and requirements
- Minimal data protection and cybersecurity principles and requirements
- Principles for policymaking and helping end-users

After the world congress of 2023, the topic could be taken over by a dedicated Technical Committee.

12 GLOSSARY

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving System
API	Application Program Interface
AV	Automated Vehicle
CAV	Connect and Automated Vehicle
C-ITS	Cooperative Intelligent Transport System
CV	Connected Vehicle
DCAT-AP	Data Catalogue Vocabulary – Application Profile
DGNSS	Differential GNSS
E2E	End-To-End
Galileo	European Global Satellite Navigation System
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
HMI	Human Machine Interface
I2V	Infrastructure to Vehicle (Communications)
ISA	Intelligent Speed Assistance
ISAD	Infrastructure Support levels for Automated Driving
LMICs	Lower and Middle Income Countries
LTA	Left Turn Assist
METR	Management of Electronic Traffic Regulations
MUTCD	Manual on Uniform Traffic Control Devices
NAP	National Access Points

ODD	Operational Design Domain
OEM	Original Equipment Manufacturers
PPP	Precise Point Positioning
Q-WARN	Queue Warning
RLVW	Red Light Violation Warning
RNO	Road Network Operations
RTK	Real-Time Kinematic
SAE	Society of Automotive Engineers
SBAS	Space Based Augmentation Systems
SF-PPP	Single Frequency Precise Point Positioning
SLAM	Simultaneous Localization and Mapping
SPaT	Signal Phase and Timing
SWIW	Spot Weather Impact Warning
TMC / TCC	Traffic Management Center / Traffic Control Center
TSR	Traffic Sign Recognition
V2I	Vehicle to Infrastructure (Communications)
V2V	Vehicles to Vehicle (Communications)
V2X	Vehicle to Other (Communications)
WZDx	Work Zone Data Exchange

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