MAVEN

Managing Automated Vehicles Enhances Network

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Executive Summary

The MAVEN Transition Roadmap presents the MAVEN project's expert views and recommendations for the transition of traffic management at signalised intersections along urban corridors from the present conventional transport world into a connected, cooperative and automated world. This vision is delivered by the MAVEN consortium.

From a road authority's perspective, the transition path to a cooperative, connected and automated world looks uncertain. Inevitably, conventional, Cooperative Intelligent Transport Systems (C-ITS) and automation equipped vehicles and roadside equipment will co-exist for some time. Vehicles will also co-exist with other types of non-motorised road users, such as pedestrians and people on bicycles and other modes.

As automated vehicles will have an impact on several aspects of daily life, such as accessibility of services and locations, road safety, environment, congestion and economic growth, local authorities will need to take account of vehicle automation in their policy making and longer-term strategic planning. There will necessarily be different policy implementations in different cities, however, there is significant value in cities evaluating their automated vehicle deployments against a common framework to ensure that policies can be delivered well, and maximum value extracted from their implementation. The Roadmap aims to assist local authorities in determining their role and responsibilities, giving special attention to the role of traffic management and its level of guidance at various phases of the transition.

The MAVEN Roadmap considers the technical, political and organisational aspects, and identifies priorities related to the safety and comfort of special category road users such as public transport vehicles, vulnerable road users, logistics vehicles, and emergency vehicles. Moreover it identifies steps to be taken by policy-makers, road-authorities, standards-development organisations and other stakeholders on the route to a high penetration of highly or fully infrastructure-supported automated vehicles.

The introduction of Cooperative Intelligent Transport Systems (C-ITS) will bring some changes to city traffic and city traffic management. Full deployment of C-ITS is still a way off for most transport authorities and cities, but some cities are moving towards this in small steps through active support of smart mobility pilots and showcases.

The Roadmap covers different perspectives of the transition to full automation and how infrastructure and road authorities can prepare for automation with the aim to offer the reader a broader understanding of the many views on possible development paths. These are derived from other research and innovation projects co-funded by the European Commission, e.g.

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CoExist, INFRAMIX, and the high-level EU Strategic Transport Research and Innovation Agenda (STRIA) Roadmap.

The transition phases range from managing the operational design domain (ODD), namely the specific operating conditions in which the automated driving system is designed to properly and safely operate, to understanding the differences between various operating environments and the how these affect the ability to deploy actual, operational, real world automated vehicle solutions within a reasonable timeframe. Another way of looking at automation is to classify and harmonise the capabilities of a road infrastructure to support and guide automated vehicles. How public authorities can prepare for automated driving is illustrated in detail by the CoEXist roadmap which has developed a CAV-ready framework for cities which proposes actions that cities can take to progressively introduce CAVs into their policy and planning processes.

MAVEN has focused on the city readiness phases and in particular has explored V2X use cases and how automated vehicles could be managed within cities to enhance both the flow of traffic as well as the safety of all road users. The various requirements and steps to transitioning to the MAVEN approach are clearly identified, with a particular emphasis on the traffic signal-related infrastructure requirements. These requirements concern the following domains: traffic control requirements; sensor requirements; communications requirements, including road-side units; physical infrastructure requirements; digital map requirements.

The three case studies which were carried out by the MAVEN project in European cities, Greenwich in London, Helmond in the Netherlands and Braunschweig in Germany illustrate different levels of city awareness and understanding of connected automated vehicles and vehicle-to-infrastructure technologies and how they could transform mobility within cities. For each city we looked at their specific transition approach, which MAVEN use cases apply and what steps are needed for implementation.

Some conclusions are drawn about what role traffic managers should have in the shift towards a new urban mobility scenario, and steps to be taken by local authorities. These conclusions and recommendations can be valuable for most traffic environments and can give guidance in environments where cooperative ITS systems will be introduced. They aim to create awareness of the changes that are going to come, to indicate where adaptations are needed and to start discussions on how to adapt to these changes.

The document is a 'stamp in time' and not a living document; therefore in a fast moving area of innovation, it should be read in the context of expected future developments in the sector.

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Abbreviations and Definitions

Abbreviation	Definition
ANPR	Automatic number-plate recognition
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Messages
CPM	Cooperative Perception Message
C-ITS	Cooperative Intelligent Transport Systems
ETSI	European Telecommunication and Standardisation Institute
GLOSA	Green Light Optimal Speed Advice
ITS	Intelligent Transport Systems
LTE	Long-Term Evolution
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SAPS	System Activated Plan Selection
VRU	Vulnerable Road User
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle-to-everything communication

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1 Introduction

The objective of this Roadmap is to be a discussion and position paper that addresses the management of intelligent and highly automated vehicles in cities in general, the role of traffic management and its level of guidance at various phases of the transition more specifically. Furthermore, it presents important considerations, and steps to be taken by road authorities, standards development organisations and other stakeholders.

The MAVEN Transition Roadmap consists of the following sections:

- **Chapter 2** describes the scope of the MAVEN project and its approach to connected automated vehicles and urban road traffic management through the MAVEN use cases;
- **Chapter 3** sets the scene by illustrating in broad terms what changes the introduction of Cooperative Intelligent Transport Systems (C-ITS) will bring to city traffic and city traffic management;
- **Chapter 4** discusses different perspectives of the transition to full automation and how infrastructure and road authorities can prepare for automation;
- **Chapter 5** focuses on the MAVEN system and describes what needs to be done to introduce it into an existing city traffic management system. This section covers key aspects such as infrastructure requirements; societal, economic and environmental requirements; organisational and traffic management requirements; and operational traffic management requirements;
- **Chapter 6** introduces three MAVEN cities examples: the city of Helmond (the Netherlands), Digital Greenwich Cities (Royal Borough of Greenwich, London, United Kingdom) and the city of Braunschweig (Germany);
- Finally, **Chapter 7** presents some conclusions about what role traffic managers should have in the shift towards a new urban mobility scenario, and steps to be taken by local authorities which are confronted with increasing automation in road transport.

The first part of this document (Chapters 2, 3 and 4) looks at the bigger picture of automation in transport, Cooperative Intelligent Transport Systems (C-ITS) as the enabling technology, what direction the future of urban road transport is taking and what city transport policy context is necessary to enable C-ITS. It also tries to position MAVEN by describing what C-ITS is and how we understand it, and which high technology vehicles we are considering.

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The second part (Chapters 5, 6 and 7) focuses on the specific MAVEN system and makes recommendation to local authorities and other stakeholders on the route to take to achieve a high penetration of highly or fully infrastructure-supported automated vehicles.

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2 The MAVEN project

2.1 Background

Automated vehicles (AVs), connected with an intelligent environment, could significantly contribute to meeting the EU objective of reconciling growing transport demand and mobility needs of people and goods with more efficient transport operations, lower environmental impacts and increased road safety in an integrated urban mobility system.

The coming years will see growth and investment in fully automating current driving tasks and the introduction of AVs, with the role of the human driver diminishing. At the same time, the deployment of Cooperative Intelligent Transport Systems technology (C-ITS)[1] will not only be a key enabler for distributed coordination of AVs but, combined with intelligent traffic management and control applications, will also enable the road infrastructure to monitor, support and orchestrate vehicle movements.

Though there are many vehicle technologies related to ITS, fully or partial AVs receive most of the attention of the general public. The foundation of the MAVEN project is that infrastructure applications will continue to play a vital role in the management of the traffic network. Similar to today's operation of traffic networks, traffic management and traffic control systems will have a coordinating, orchestrating and sometimes dictating influence on traffic flows and dynamics, in support of societal and collective objectives. For example, infrastructure applications may organise the formation of dynamic platoons, set targets for such platoons, but leave the details of its progress to the platoon as a self-organizing unit.

In this context, the MAVEN project is developing and testing cooperative automated driving applications at the crossing of:

- **Infrastructure versus vehicle systems' authority;**
- **Global versus local and societal versus individual users' objectives;**
- **Traffic light optimisation versus vehicle trajectory and manoeuvre optimisation.**

2.2 Definitions

MAVEN is considering different types of vehicles, which vary in their automation and connectivity capabilities:

[1] Standardised platform for communication between vehicles and vehicle-infrastructure.

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- **Cooperative non-automated vehicles** are assumed to be ETSI ITS G5[2] equipped vehicles without level-4 automated driving capabilities. In MAVEN, cooperative non-automated vehicles use V2X communication to announce their presence, status and dynamics to other cooperative vehicles and to the cooperative intersection, i.e. an ETSI ITS G5 equipped intersection. A cooperative non-automated vehicle can be any type of vehicle, for example a car, bus or truck and any vehicle class, for example a regular passenger vehicle, priority vehicle or emergency vehicle.
- **Automated Vehicles** are assumed to be equipped with level-4 Advanced Driver Assistance Systems (ADAS) which can perform all aspects of the driving task with or without the attention of the human driver. Automated Vehicles use vehicle-sensors to monitor the near surroundings of the vehicle and make driving decisions independently (i.e. autonomously). They are not equipped with ETSI ITS G5 communication capability, therefore are not connected nor cooperative.
- **Cooperative Automated Vehicles** are assumed to be ETSI ITS G5 [1] equipped vehicles with level-4 automated driving capabilities at signalised intersections. In this sense, they are improved versions of cooperative non-automated vehicles. Cooperative Automated Vehicles use vehicle sensors and V2X receivers to monitor the surroundings of the vehicle, and V2X communications to interact with other cooperative vehicles and with cooperative intersections. A cooperative automated vehicle can be any type of vehicle, for example a car, bus or truck and any vehicle class, for example a regular passenger vehicle, priority vehicle or emergency vehicle. Multiple Cooperative Automated Vehicles may form a platoon and assume one out of two roles: platoon leader or follower. The platoon leader interacts with the environment on behalf of the platoon, whereas the followers primarily interact with the platoon leader. Within MAVEN this vehicle category can also be referred to as a highly automated vehicle.

2.3 The MAVEN approach

The US Society of Automotive Engineers' (SAE) standard provides and defines the six levels of driving automation, from no automation to full automation. Some of the lower levels of automation are already being offered in newer cars today, through systems such as adaptive cruise control or parking assistance. Rather than providing full autonomy, these systems were designed to support the driver, who remains in full control of the vehicle.

[2] ETSI ITS G5 is a standard by the European Telecommunications Standards Institute for vehicular communication technology operating in the 5 GHz frequency band and supporting ITS applications.

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MAVEN is developing solutions for **managing level 4 highly automated vehicles at (urban) signalised intersections,** including **algorithms for infrastructure-initiated guidance of highly automated vehicles** using negotiation protocols between vehicles and the infrastructure. Iteratively, highly automated vehicles receive advice and/or commands from the road infrastructure to adjust their trajectory and manoeuvring policies, while the infrastructure dynamically adapts the traffic light timing of single or multiple signalised intersections based on the anticipated vehicle arrival pattern. The project is building a system prototype that is to be used both for field tests and modelling. Furthermore, it is contributing to the development of enabling technologies, such as telecommunication standards and high-precision maps.

Based on the project findings and views obtained from stakeholder consultation meetings[3] with local authorities, road authorities, and other urban road stakeholders, this Roadmap for the introduction of **infrastructure-supported road transport automation** is being developed, to support road authorities in understanding potential **future changes in their role and in the tasks of traffic management**.

Finally, a MAVEN **guide on the "management of automated vehicles in a smart city environment" has been published and which positions the MAVEN results in the broader perspective of transport in smart cities** and embeds these with the principles and technologies for smart cities, as well as service delivery.

2.4 MAVEN use cases

A use case defines the interactions and desired behaviour of the system and external actors under the specification of system boundaries and usage scenarios. Each of the sixteen use cases defined by MAVEN describes the high-level functionality and expectations of the MAVEN project, and are designed to be understood by different stakeholders, particularly technology companies and local authorities. They are broken down further into particular requirements, thereby forming the basis of the MAVEN functionality. A short overview of the topic-clustered MAVEN use cases follows.

[3] The first MAVEN stakeholder consultation with local authorities and urban road stakeholders took place in Barcelona on 15 November 2016, and two joint CoEXist / MAVEN / TransAID workshops on the implications of vehicle automation for city and regional authorities were held in Brussels on 10 October 2017, and Greenwich on 24 October 2018.

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Table 1: MAVEN use cases

Use cases cluster	Description
Platoon management	There are six use cases (1-6): forming a platoon; joining, travelling and leaving a platoon; platoon break-up and termination.
Speed change advisory (GLOSA)	Calculating speed advice based on signal phase and timing information.
Lane change advisory	Distributing vehicles over the available lanes to make optimal use of the road capacity.
Emergency situations	Mitigating the risks of unexpected events and to ensure traffic safety.
Signal optimisation	There are five use cases (10-14): balancing the priorities according to the policies set by the road operator; queue length estimation; local level routing; green wave; and signal optimisation.
Negotiation	Performing a bi-directional exchange of information for negotiations using communications from infrastructure and vehicles and back.
Detect non-cooperative road users	Detection and characterisation of complementing non-cooperative road users (vulnerable road users, non-cooperative vehicles) for their inclusion in relevant use cases.

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3 Setting the scene

Vehicle automation is receiving a significant amount of attention in the press and media, at policy level and increasingly from the general public. Automated vehicles will have an impact on several aspects of daily life, such as accessibility of services and locations, road safety, environment, congestion and economic growth. Therefore, local authorities will need to take account of vehicle automation in their policy making and longer-term strategic planning. **MAVEN can make a valuable contribution to this exercise in terms of traffic management**, including the expected change to the role and responsibility of the traffic manager in an inerasably automated system.

3.1 Urban mobility, economic & environmental policy today

Automated vehicles have the potential to change how people travel in the broadest sense and to impact on other key **policy areas.** There will necessarily be different policy implementations in different cities, however, there is significant value in cities evaluating their automated vehicle deployments against this common framework to ensure that policies can be delivered well, and maximum value extracted from their implementation. More details about a city transport policy context and MAVEN's vision can be found in Chapter 5.3.

In Chapter 6 some cities (Helmond, Royal Borough of Greenwich, and Braunschweig) give their view on these aspects in relation to automated vehicles. This exemplifies that different cities will have different views, but all agree that **city authorities should think about the future of the mobility systems as automated motoring advances and should incorporate this in their policies and plans**.

3.2 Traffic management today

The main purpose of urban traffic management is **to optimise the flow of people and goods on roads, essentially using different traffic signal configurations** to maximise vehicle throughput at signalised intersections. In addition to traffic signals, the traffic manager can use other tools, notably **Intelligent Transport Systems (ITS)**, to influence driver behaviour by providing information such as travel times, route guidance, roadworks/congestion warnings or special events.

Such optimisation must increasingly align with a range of other transport policies, such as emissions reduction, safety of all road users, especially vulnerable road users, economic regeneration and social cohesion. For instance, the traffic manager must now seek to integrate

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public transport priority and improved road access for pedestrians and people on bicycles and other modes into the task as well as measures to reduce vehicle emissions.

Furthermore, a combination of market developments and new internal policies mean **the traffic manager is no longer alone in managing the roads and guiding vehicles**. For instance, growth in in-vehicle navigation systems has meant that drivers can choose the route that is best suited to their needs independently of the traffic manager's preferences. The move to making public data open, including transport data, is accelerating this trend as more and more third-party information service providers appear on the market and the role of the city authority as traffic and travel information service provider diminishes.

3.3 C-ITS and cities today

Currently, vehicles are being manufactured with an increasing number of driver assistance systems, but they do not yet interact with each other or with the roadside. This interaction is the domain of Cooperative Intelligent Transport Systems (C-ITS) which will enable equipped vehicles and traffic managers to share information and ultimately to coordinate their actions.

The cooperative element, enabled by wireless data transmission between vehicles and between vehicles and the infrastructure, may lead to improved road safety, reduced congestion and improved driving comfort by assisting the driver to take the most appropriate decisions and become more adaptable to various traffic situations. As a traffic manager, infrastructure owner and operator, transport operator and information service provider, **city/regional authorities are important users and therefore buyers of ITS**. C-ITS can certainly add to the existing ITS mix.

While the general feeling from transport authorities towards C-ITS is one of caution [3], some cities, notably those involved in European and national pilot projects, are pushing ahead with further piloting and (pre)deployment. Greenwich (London, United Kingdom) for instance, could initiate the move towards testing and deploying C-ITS systems as part of the Smart Mobility Living Lab: London, a Connected Autonomous Vehicles test bed that is being built in the borough in 2018-19. Full deployment of C-ITS is still a way off for most transport authorities and cities, but some cities are moving towards this in small steps through active support of smart mobility pilots and showcases such as MAVEN.

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4 Transition

One common desire across all stakeholders, both public and private, is to exploit the full benefits of connected and automated driving in terms of safety, efficiency and the impact on the environment. The global vision is that automated vehicles, connected vehicles and Cooperative Intelligent Transport System (C-ITS), together, will lead to more sustainable mobility (i.e. reduced road fatalities, optimal traffic flow, reduced emissions, reduced congestion and social inclusiveness). This section provides different perspectives of a cooperative automated future, based on results from other European initiatives. The selected material is relevant to understand the wider scope of MAVEN-like solutions, the transition towards them as well as their implementation.

4.1 Towards cooperative, connected and automated mobility

There are many views on possible development paths, likely roadmap and intermediate phases. The European Commission has illustrated the path towards cooperative, connected and automated mobility as shown in Figure 1 below [4]. What is interesting about this figure from the perspective of MAVEN are the labels “negotiate” and “orchestrate” which is literally what MAVEN use cases aim to achieve.

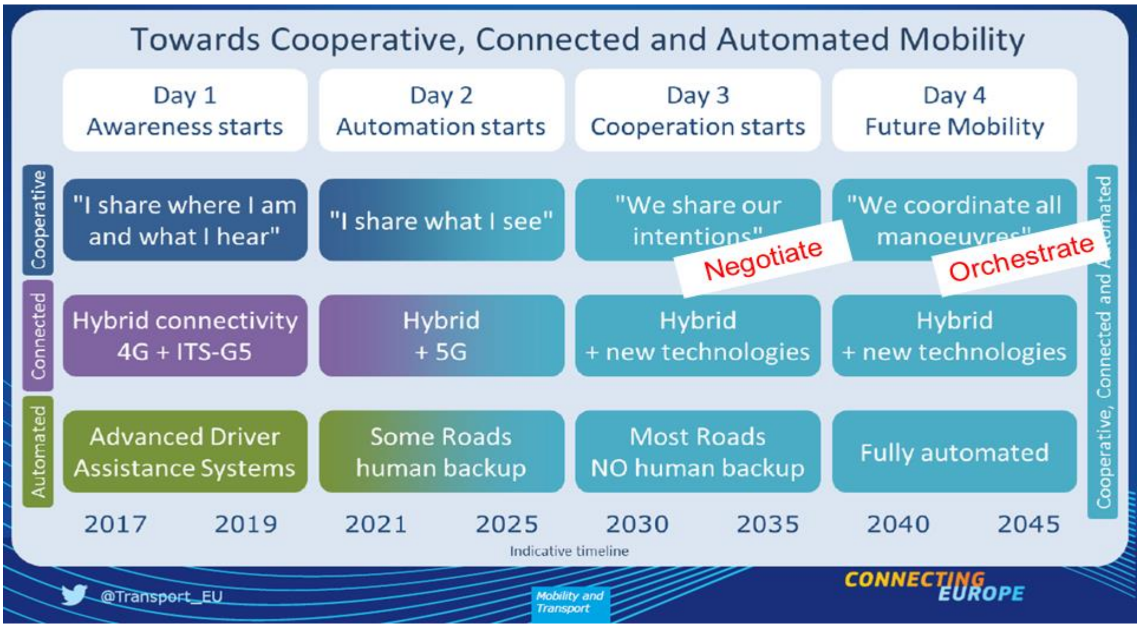

Figure 1: Path towards cooperative, connected and automated mobility.
Source: European Commission, DG MOVE, 2018

To better understand the framework of cooperative, connected and automated mobility, it is relevant to know the distinction and interrelation of these terms, as they are often confused.

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Building on the definition provided in section 2.2, we consider that [5]: *connected driving* itself does not necessarily imply *cooperative driving*. Single traffic participants can theoretically use the additional information for their own individual advantage at the cost of others. Similarly, *autonomous driving* does not intrinsically cause improved traffic. If everybody decides on his own without a *cooperative coordination* with other traffic participants, then chaos and traffic collapses may be a consequence. Normally, autonomy is only appropriate in the case of low densities. *Automated driving* can lead to significant improvements in traffic, because *cooperative behaviour* can be enforced for robots much easier than for human beings. Robots follow their instructions much more precisely than humans, unless these are autonomous robots which decide to do differently.

4.2 Managing the Operational Design Domain

What is relevant about the expected benefits of cooperative, connected and automated driving and when they become available is the operational design domain (ODD) of automated vehicles. ODD is a description of the specific operating conditions in which the automated driving system is designed to properly and safely operate, including but not limited to roadway types, speed range, environmental conditions (including weather, daytime/night time), prevailing traffic law and regulations, and other domain constraints [6]. Any automation use case of level 1-4 is usable only in its specific ODD. An ODD can be very limited, for instance a segregated road or a single fixed route on low-speed public streets. A graphical representation of the ODD with a storyline is shown in Figure 2 below [7].

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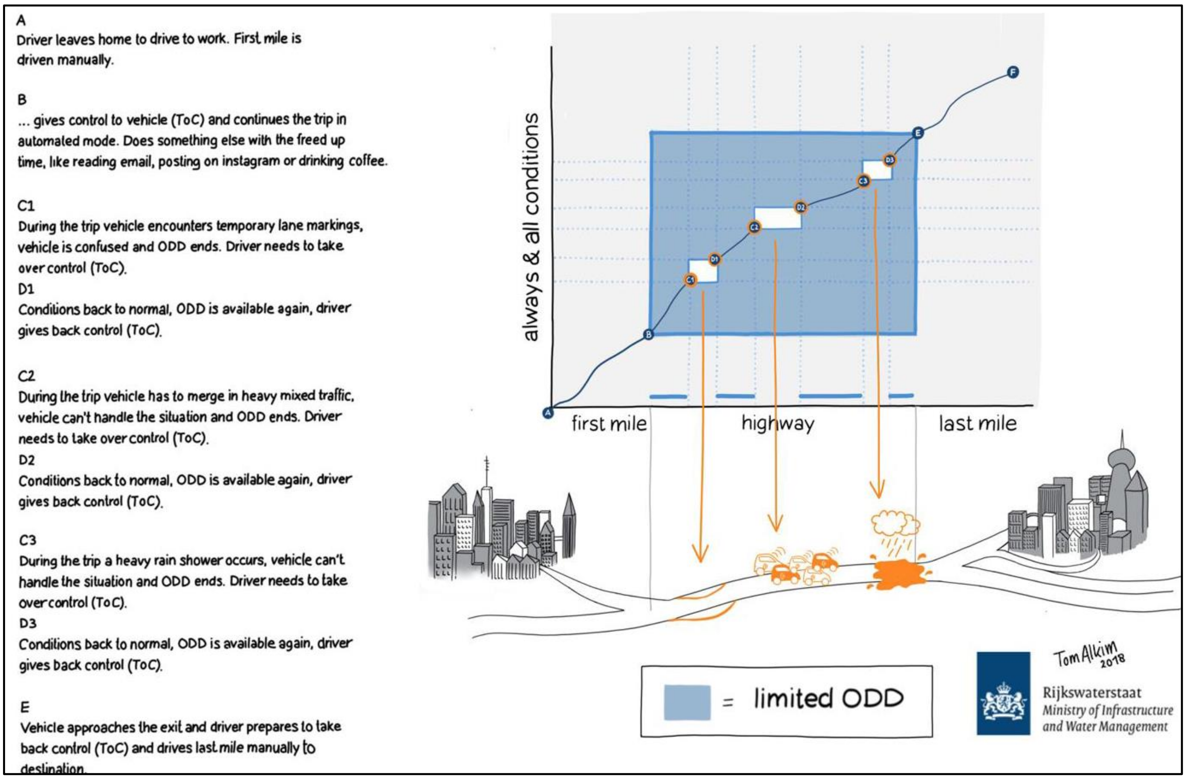

Figure 2: Visual representation of operational design domain (ODD). Source: STRIA Roadmap on Connected and Automated Transport: Road, Rail and Waterborne [7].

The attributes of the ODD are directly connected to the way the automated driving system works and the interaction with its environment. An important aspect to realise about the ODD is that there is not one stakeholder who can affect all specific conditions, let alone control them. Therefore, a vehicle manufacturer cannot guarantee that a level-4 vehicle can always drive in L4 mode, but only inside the ODD. And similarly, a road operator would not be able to offer a road on which a L4 vehicle can be guaranteed to drive in L4 mode because factors outside their control (such as adverse weather conditions) may prevent that. However, a mutual goal amongst stakeholders could be to "manage" the ODD, making it as uninterrupted, stable and predictable as possible, in order to allow as much automated driving as possible thus maximising the potential benefits that are associated with it. This implies that actions by both vehicle manufacturers and public authorities can help to preserve and extend the ODD of automated vehicle geographically and temporally.

The above implies that the path from no automated to full automation, in fact has two dimensions: the increase of the automation level and the expansion of the use area as shown in Figure 3 below.

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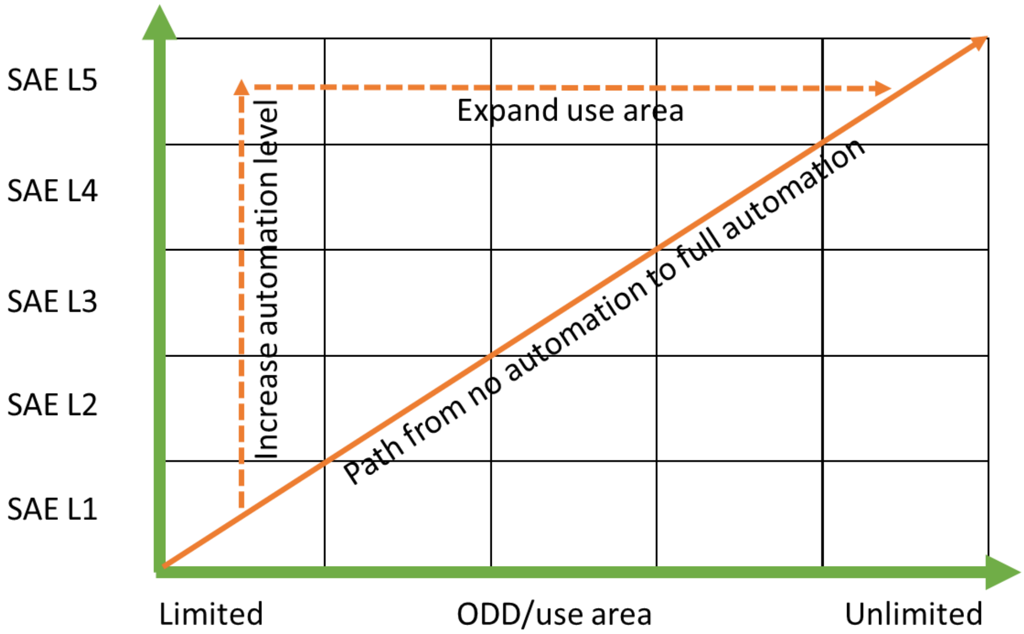

Figure 3: automated levels versus the ODD use area. Courtesy MAPtm.

The central question related to Figure 3 and the different stages it represents is: *what attributes mark the boundaries of these stages, and what is needed to enable a transition to the next level?*

4.3 Operating environment

To answer the above question, it is relevant to understand the differences between various operating environments and the how these affect the ability to deploy actual, operational, real world automated vehicle solutions within a reasonable timeframe. To appreciate the difference between controlled, semi-controlled and uncontrolled environments, four key areas need to be considered [8]:

- **Speed:** how fast is the vehicle moving and other vehicles in its vicinity? At lower speeds everything is always easier, especially when nearing intersections.
- **Intersections:** does the vehicle need to deal with cross traffic, other cars or vulnerable road users? Are the intersections on a grade? Is the traffic in them regulated, and if so, how much control is there over the traffic flow?
- **Access:** is the vehicle segregated in its own separate lane or pathway, or does it need to share the lane with other vehicles? How likely is it that there will be people or vehicles in the lane that are not supposed to be there? What other vehicles does the automated system need to share its lane with? Sharing part of the street infrastructure with a human-driven bus is much easier than with random traffic and pedestrians.

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- **Behaviour:** how much control is there over how people use and interact with the system? Human nature dictates that people will always be disobedient and ignore traffic signals. Who are the users?

Differences in these four areas denote a continuous scale from fully controlled to uncontrolled environments. At one end of the scale is a people mover system operating on private premises along its own track or pathway. At the other, a fully autonomous driverless vehicle navigating busy city streets amongst other traffic. In this sense, car manufacturers and tech-giants talking about automated cars being deployed in the upcoming years (2020-2025) are talking about highways. A highway is an environment where all vehicles travel at approximately the same speed, have no at grade intersections, with access restricted to cars and behaviour being relatively similar. It is basically a semi-controlled environment and certainly very different from a city centre where cars, trams and buses, people on bicycles and other modes, and pedestrians create an uncontrolled environment, which is much less predictable and more complex.

Another way of classification that builds upon the previous sections, comes from the European Research and Innovation Programme Horizon 2020 INFRAMIX project, which has developed a scheme similar to the SAE levels for automated vehicle capabilities, only then for digital infrastructure. The so-called Infrastructure Support Levels for Automated Driving (ISAD) aims to classify and harmonise the capabilities of a road infrastructure to support and guide automated vehicles [9].

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

Figure 4: Infrastructure Support Levels for Automated Driving (ISAD). Source: INFRAMIX [9]

What is particularly interesting is the interplay between the ODD, the SAE automation levels, the ISAD. Clearly, they are related but not interchangeable nor perfectly compatible. Again, for

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a holistic approach the involvement, collaboration and cooperation between relevant (inter)national parties involved in automated driving is required. Involved parties are e.g. different sectors in industry, utilities, infrastructure providers, academia, public authorities.

4.4 Automation readiness

So how can public authorities prepare for automated driving? What can they do to facilitate, anticipate and/or regulate automated driving? Various initiatives have been trying to identify and structure possible actions that cities can take to progressively introduce automated driving.

One of them is the European Research and Innovation Programme Horizon 2020 CoEXist project (www.h2020-coexist.eu) which has developed a CAV-ready framework for cities which proposes actions that cities can take to progressively introduce CAVs into their policy and planning processes. Three phases have been identified: (1) becoming CAV aware; (2) planning for automation (including defining measures), and (3) implementation of measures. A range of actions are proposed according to the three phases and considering different mobility aspects: policy, planning, infrastructure, capacity building and traffic management.

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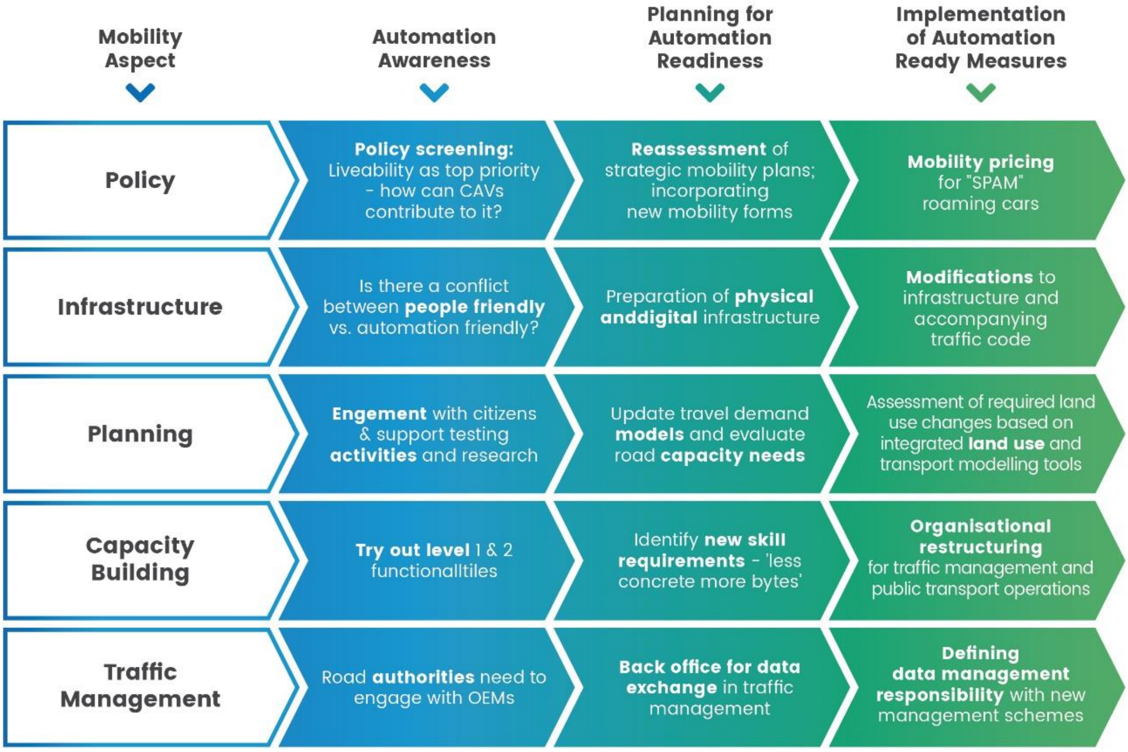

Figure 5: Overview of three phases towards automation-readiness with examples of measures. Source: European Research and Innovation Horizon 2020 CoEXist project (2019), Automation-ready framework, version 1

The MAVEN project has leveraged the work of the CoEXist project with particular focus on the "transition" and complemented this work through exploring V2X use cases and how traffic automated vehicles could be managed within cities to enhance both the flow of traffic as well as the safety of all road users.

Below, transitions as seen from the perspective of MAVEN are further detailed according to the readiness phases as proposed by the CoEXist project and shown above. The questions and requirements that are listed were collected during MAVEN stakeholder consultation workshops or taken from the inventory of requirements for C-ITS deployment of the CODECS project [3].

Automation-awareness for management of automated vehicles:

- Understand need, urgency and system functionality.
- Build understanding of use cases and their benefits (if any) in relation to existing approaches/technologies.
- Start reflection on changes to traffic management task and role of traffic manager.
- Does my city/regional authority have a policy on AVs?

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- What if I do nothing?

Planning and preparation for management of automated vehicles:

- Policy & regulation: form an opinion, assess strategic plans and define a course.
- Traffic management strategy assessment:
  - How will cooperative perception and cooperative driving help me to do my job better as traffic manager?
  - Which use cases hold most value for my city/region? Will the benefit be greater if implemented together or can it be done incrementally?
  - Which intersections/corridors should be prioritised?
  - How will my role as traffic manager evolve? What influence will I have on vehicle movements as automated motoring advances?
- Organisational change assessment:
  - Do traffic management staff have the right knowledge and skills?
  - How will the use cases affect existing traffic management procedures?
  - New guidelines for vehicle guidance and control may be needed.
- Traffic management infrastructure assessment:
  - Traffic signals readiness.
  - Is additional infrastructure needed.
  - Integration with legacy systems, systems upgrading?
- Procurement:
  - Market readiness: are the infrastructure systems on the market already?
  - When will equipped vehicles be there in sufficient numbers to justify action/investment?
  - Procurement guidance is needed.
- Digital data assessment:
  - Digitise infrastructure – what, who and how?
  - Provide access to traffic & infrastructure-related data (i.e. enabling ISAD level D/C).
- Business plan development:
  - What benefit will it bring?
  - How much will it cost and who will pay?
  - What if I do nothing?

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Implementation for management of automated vehicles

- Implement the basic infrastructure necessary to enable cooperative perception (i.e. enabling ISAD level B).
- Implement the advanced infrastructure necessary to enable cooperative driving (i.e. enabling ISAD level A).

4.5 Gap analysis

As part of considering a transition roadmap for cities to enable them to prepare for an automated vehicle future, it is important to understand where existing cities and authorities are in terms of awareness, readiness and implementation. The MAVEN project has carried out three case studies in European cities: Greenwich in London, Helmond in the Netherlands and Braunschweig in Germany, to understand their awareness and understanding of CAVs and vehicle-to-infrastructure technologies and how they could transform mobility within cities.

The CoEXist framework of city readiness has been used to assess the three cities awareness, readiness and implementation of automation ready measures. Each city has been graded in each category on a 3-point scale from no progress though partial progress to ready for each stage. These full analyses are included in chapter 6.

Based on the three case studies, it is clear that these cities are making progress in terms of their awareness of CAVs and Mobility as a Service (MaaS) and the traffic management implications of these paradigm shifts. It is also clear that other cities will be partially progressed in each of these categories and other cities may be equally progressed or even more progressed in certain areas. The purpose of the exercise was not to compare cities relative progress against each other, but rather to validate the need for a transition roadmap for cities to achieve CAV and MAVEN readiness.

For cities to adopt MAVEN style approaches and use cases, it is clear that there will need to be investment in each of the areas identified within the CoEXist work. We can summarise this as follows:

- **Policy** - Cities are variably aware of the need to build knowledge around CAVs and MaaS, particularly from a policy perspective. If cities are to avoid being left behind as the market transitions to CAVs and MaaS, it is imperative that cities and policy makers understand what these technologies could enable and how they might influence future lifestyles and behaviours. CAVs present significant opportunities to reduce private car

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ownership and single occupancy journeys, if correctly supported by policy makers, which would have clear benefits to cities in terms of reduced congestion, improved air quality and a generally improved public realm.

- **Infrastructure** - It is clear that digital connectivity is the underpinning infrastructure required to enable any "Connected" application that forms the "Connected" part of Connected Autonomous Vehicles. Fibre and 5G are the base level technologies required to deliver both the bandwidth and latency required for robust management of CAVs. Cities and the private sector are at varying levels of coverage for fibre across Europe and 5G is still in development as a technology (as of 2019). Cities will need to continue to work with infrastructure providers to ensure greater levels of connectivity. Cities are, however, more progressed in deploying V2X technologies that enable communications with, and the potential management of, CAVs.
- **Planning** - Cities are similarly progressed in planning as they are to their progress in policy making, with the two being closely related. There is a significant opportunity for cities to leverage both resident views and invest in modelling capabilities to ensure that services are designed with a focus on people as well as being able to quantify the benefits of different future scenarios to enable better policy and decision making relating to CAVs and MaaS.
- **Capacity building** - Cities have demonstrated different approaches to capacity building, with some building in-house capabilities and others ensuring that outsource partners are required to build capability on the City's behalf. The cities studied are well progressed in terms of capacity building, which demonstrates that it must lead development in other areas. Cities should look to increased sharing and collaboration to spread the resource load associated with this capacity building.
- **Traffic Management** - This is the least developed area of competence for the studied cities. While this is not an issue at present, as no fully automated vehicles are operating on European roads, this is an area of significant opportunity for development and validates the need for this transition roadmap as part of the MAVEN project. Cities, their outsourced partners and industry, including MaaS operators, will need to further collaborate on future traffic management capabilities and how traffic management technologies and practices will need to be transformed and developed to allow for the implementation of policies emerging in this area.

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5 Main requirements for implementing the MAVEN approach for connected, cooperative and automated transport

Transitioning to the MAVEN approach means taking the steps (technical, technological, organisational, policy, etc) required to enable the MAVEN use cases to be implemented in a city. This chapter describes in detail the various requirements, with a particular emphasis on the traffic signal-related infrastructure requirements.

Since infrastructure and traffic management are the focus of MAVEN, vehicle requirements are not addressed in this document, except in terms of communication.

5.1 Infrastructure requirements

MAVEN identifies the requirements to deploy level-4 automated vehicles which need to be understood by traffic and road managers. These requirements concern the following domains:

A. **Traffic control requirements:** Target the interaction and synergy between C-ITS use cases and traffic control algorithms;
B. **Sensor requirements:** Assist the system detecting vulnerable road users and non-equipped vehicles during the transition phase from conventional to cooperative and automated driving;
C. **Communications requirements, including road-side units:** Providing access to information from the infrastructure between different infrastructure components;
D. **Physical infrastructure requirements:** Enable automated vehicles to recognise the road topology and its regulations through clear lane markings and traffic signs;
E. **Digital map requirements:** Complement the physical infrastructure requirements by providing a detailed digital map of the environment.

Figure 6: Autonomous vehicle test in Braunschweig. Courtesy: DLR

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5.1.1 Traffic control requirements

The requirements related to the traffic controller depend directly on the type of control algorithm deployed. There are five types of traffic control, these are fixed time control, actuated control, semi-fixed time control, adaptive control and the newly introduced stabilised adaptive control.

- The most basic form of control is **fixed-time control**. There is **no need for investment in sensors** and **the controller itself needs little processing power**. Operating and investment costs are therefore low. However, if traffic demand changes, a new plan is required. The controller can be upgraded using specific time-of-day plans and some sensors can be added to the network for dynamic switching between different static plans.
- For **actuated control** the algorithm is very simple, but **sensors are required for each lane near the stop line**. This is a significant investment. A green phase can be skipped when no traffic is present. Once a light is green, the sensors continuously check if more traffic is coming and cut off the green phase when this is not the case.
- **Semi-fixed time control** is a hybrid between actuated and fixed-time. Only the last part of a green phase is controlled by sensor status. This helps in maintaining synchronisation in case of a green wave and is currently considered most suitable for Green Light Optimal Speed Advice (GLOSA).
- **Adaptive control** relies on a model of the approaches towards the intersection. This means the **investment in sensors is even higher than for actuated control**, because vehicles have to be detected further upstream. This gives the best performance in terms of traffic efficiency and allows the traffic manager to apply policy targets directly to the model instead of having to calibrate green durations. Therefore, it is also possible to add a policy target for plan stabilisation to make this control mechanism more suitable for GLOSA. This variant will be called "**stabilised adaptive**".

Not all MAVEN use cases require the most advanced traffic control algorithms. The platooning use cases do not depend on traffic control, while the lane advice and safety use cases depend purely on sensor presence. Queue modelling and routing combine well and can be applied on top of any control strategy, as long as it has an interface available to share its status. For negotiation, signal optimisation and priority management, either actuated or adaptive control is required, otherwise the controller doesn't have room to adjust its plans according to the extra information the vehicle delivers.

Speed change advisory is technically possible on any control algorithm that has an interface to access signal predictions, but its performance will be best with static control. In general, less

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flexibility will result in better performance and a more detailed underlying model will also result in better performance. MAVEN developed two enhanced algorithms to cope with the trade-off between flexibility and predictability, these are AGLOSA for actuated control and a stabilised adaptive method that focusses on increasing the confidence of the time to green prediction.

Green waves are also possible on any control method. A key element here is that an offset between two consecutive intersections can be nearly guaranteed. The higher the required success rate of a green wave, the less flexibility is possible. The developed design guidelines of MAVEN can be applied to all strategies.

With respect to the current deployment of traffic controllers, the regional differences are large. Scandinavian countries, the Netherlands and the United Kingdom have a large installed base of both actuated and adaptive controllers, with large cities generally using adaptive control more often. Other countries have a more scattered installed base where it really depends on the policies of the local authorities. One city could have modern adaptive control, while a neighbour is still running static controllers.

5.1.2 Sensor requirements

The sensor requirements are assuming a **transition situation where any number of vehicles between 100% and 10% are not cooperative (and automated)**. The sensors can use any technology (e.g. camera, loop detector, radar, etc.) and should indicate the presence of vehicles in an area of road small enough to count vehicles. If the area is too big, multiple vehicles can be detected as one, leading to vehicle under-counting.

- **Sensors are required for queue modelling** to measure the amount of non-connected vehicles at strategic locations. In general, inflow and outflow towards the intersection is detected at the stop line and at the entry of a link.
- The **queue length in different lanes can be measured with special sensors** to determine which lane has the shortest queue, and therefore advising approaching vehicles.
- Lastly, the **detection of non-cooperative road users** requires sensors that can detect these traffic participants. This focusses on vulnerable road users and requires the detection of presence in a certain defined area where a conflict can occur.

Queue length estimation, lane change advisory and detection of non-cooperative road users fully depend on sensors. Due to the relatively high cost of ownership, it should be carefully planned where these sensors would be most effective.

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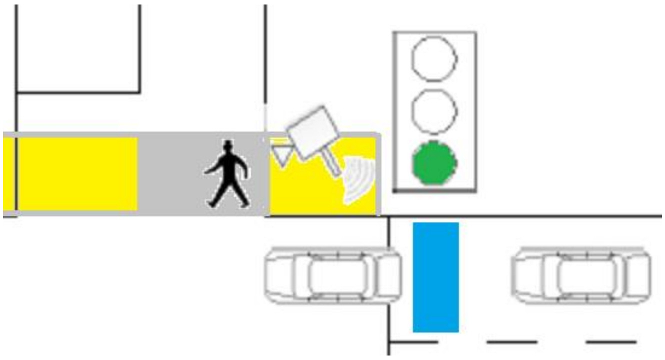

Figure 7: Sensor deployment example

In Figure 7 a typical intersection situation shows where a sensor would be beneficial. The blue rectangle indicates a stop line loop detector, which is required for queue modelling or to detect presence for adaptive and actuated control. The traffic light for crossing VRUs shares the green phase with motorised traffic that should yield for them. These situations are often challenging for the sensors of automated vehicle due to the presence of objects between the road and the foot and bicycle paths. An infrastructure sensor helps in this situation, it should be installed at an altitude of more than 3 meters to look over moving objects, which is another advantage with respect to vehicle sensors.

Figure 8: A screenshot of the MAVEN Infrastructure simulation video

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5.1.3 Communications requirements

The communication requirements for MAVEN are related to the capability of providing automated vehicles, the traffic light controller and the traffic management centres with the necessary information to execute the MAVEN use cases.

- **Communication requirements for the traffic light controller and the traffic management centre:** The traffic light controller should have a **communication interface to vehicles via a road side unit and another one to the traffic management centre**. This is needed to share all available data such as: traffic light status, prediction for future status, detector status, etc. **Sufficient processing power is required to process data** from the traffic light controller and construct messages to be sent by the road side unit.
- **Communication requirements for vehicles and the traffic light controller:** From a vehicle perspective, the communication requirements deal with the **capability of automated vehicles to be connected with the road infrastructure over the wireless medium**. The interface in this context is V2X communication, namely a road side unit based on the ETSI ITS G5 access technology and using standards-compliant communications protocols on the top of which the MAVEN extensions are built. **Pre-existing RSUs can be used** since the communication hardware is the same. MAVEN only changes the software, which means upgrades will be relatively cheap.
- **ITS-G5 and other communication channels:** MAVEN infrastructure to vehicle use cases rely on the use of ETSI ITS G5, which is the only V2X technology currently commercially available and already partially deployed. **As V2X technology evolves in the future, local authorities will need to input to, and align with, standards adopted by the car and telecommunications industries**. As vehicles become more automated, they will run an increasing number of coexisting services and use case scenarios that will require the use of **additional radio channels**, as well as complementary and/or redundant communication technologies. These technologies will range from the **enhancement of IEEE 802.11p (ITS G5) to dedicated 5G cellular solutions** ensuring redundancy and quality of service to demanding automated driving applications. This implies that, in the long term, upgrades of the deployed roadside units might include use of additional radio channels (most commercially available roadside units already support this capability) and the addition of better performing radio chips or even use of cellular solutions.

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As automated vehicles will strongly rely on the information provided by the infrastructure to automatically execute manoeuvres, **local authorities will need to ensure that the deployed road side units are capable of operating in compliance with reference specifications and minimum performance requirements and** select suppliers that have passed commonly recognised conformance tests and hence can be trusted by the vehicles.

5.1.4 Physical infrastructure requirements

Local authorities must make sure that the road infrastructure provides:

- **Quality of lanes and lane markings:** All lanes need to be marked clearly and to a high quality. Although vehicle sensors and automation system's hardware are designed for robustness, they are nevertheless sensitive components. The risk of failing components gets higher the lower the quality of the lanes is. The most important part of the lanes for automated vehicles is a standardised (dependent on the country) way of using lane markings.
- **Usability of traffic signs:** All traffic signs (static and dynamic) need to be clearly readable, fully unhidden and maintained in compliance with national laws.
- **Availability of reference points:** Conventional satellite positioning systems do not have the absolute accuracy needed for automated driving. This is especially true in street canyons, tunnels or in general on roads with limited free view to the sky. Therefore, further systems for triangulating the exact position of the vehicle are used. Most of these systems are based on landmarks. In some cases, landmarks might not be present in the needed frequency. Therefore, additional landmarks have to be identified and/or placed within the roadscape. Nevertheless, such landmarks are not standardised currently, making it difficult to formulate precise requirements.

5.2 Digital map requirements

Digital high precision maps are used in automated vehicles so they can understand their broader surroundings, match their position in it, and plan the correct trajectory and route. This leads to three major requirements for future mapping products and services:

- **Precision:** The digital map needs to be of high precision;
- **Reliability:** The digital map needs to be always up to date;
- **Localisation possibility:** Localisation of the vehicle on the digital map needs to be possible.

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To ensure these requirements are met, **local authorities need to interact with digital maps providers to support the provision and maintenance of the road network mapping with features and conditions suitable for automated driving systems**. This includes ensuring consistency of actual lane markings within high precision maps, ensuring the consistency of provided information (e.g. speed limits, C-ITS MAP lane/signal group ids), as well as proactively providing info to high precision map providers regarding road reshaping plans.

5.3 Transport policy requirements: Societal, economic and environmental

Automated vehicles have the potential to significantly impact and change how people travel in the broadest sense, including the following **policy making areas**:

A. Road Safety

This is a key aspect in a city's transport policy. Significant progress has been made over multiple decades towards "Vision Zero" (zero fatal accidents in traffic), but there is more work still to do to realise this vision. Even in countries such as the Netherlands, with an active policy on improving road safety, more than 600 people are killed in road traffic accidents each year. That figure has been rising in recent years, potentially due to factors such as an ageing population and more use of electric bikes.

Automated vehicles should contribute to increased road safety, and increased road safety should be achieved for all road users, including vulnerable road users, not only car drivers. MAVEN would need to demonstrate equivalent, ideally improved, safety for pedestrians, cyclists and motorcyclists at signalised junctions. This would require vehicle OEMs to demonstrate that AVs are at least as safe as human driven cars. MAVEN could further enhance this level of safety through grid-to-vehicle and vehicle-to-vehicle communication of hazard detection, leading to platoons having greater knowledge of the environment as a whole compared to individual vehicles.

B. Traffic efficiency and environmental impact of transport

There is a strong correlation between traffic efficiency and the environmental impact of traffic. In general, cities are aiming at optimising the use of existing infrastructure before building large scale new infrastructure. Optimal flows of traffic with minimum congestion at a network level will also have a positive impact on mitigating the environmental impact of traffic. Automated vehicles should contribute to increased traffic efficiency and minimal environmental impact.

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C. Modal split

Cities have different policy views on modal split. Some cities have the concept of co-modality, which is aiming at using the most optimal mode of transport for a specific goal, without limiting freedom of choice and mobility opportunities of the citizens. Other cities are actively promoting more sustainable modes of transport, such as walking, cycling and public transport.

Cities shall consider:

- The impact of AVs on the modal split, by means of simulation studies;
- Opportunities of AVs to make a shift to more sustainable modes of transport (e.g. automated shuttles for last mile services, car sharing concepts)
- Be aware of possible negative impact of AVs on modal split (e.g. more use of private cars).

D. Urban planning and urban land use

AVs present significant long-term opportunities in terms of land use and spatial planning. It is well established currently that privately-owned vehicles are parked for in excess of 90% of time. If transport services, enabled by automation triggered ownership and usage norms, can help reduce private car ownership and single occupancy journeys, less road space will be needed allowing for land to be re-purposed for pedestrians, cyclists and other public space use over time. To avoid the converse (more private car ownership and increased single occupancy journeys), policy makers need to explore ride-sharing opportunities and plan urban developments and re-developments in such a way as to reduce the need for car-based journeys in the first place.

E. Public acceptance

The acceptance and compliance of drivers are crucial, as it emerged from the MERGE (AV Rideshare) and the GATEway trials in Greenwich [10].

Additionally, an online survey will be prepared including video material that captures the concepts of MAVEN to evaluate the opinion of the general audience. Additionally, citizens of the pilot cities will be invited to drive in the test vehicles as a passenger.

Finally, and also at the pilot sites, the acceptance of drivers in unequipped vehicles surrounding the automated ones will be assessed by asking participants to follow and observe the behaviour of the test vehicles.

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In order to address the driver perspective and evaluate end-user satisfaction, end user surveys will be conducted. This includes participants of the field tests (drivers of automated vehicles, as well as drivers of unequipped vehicles) as well as general public, especially citizens on the participating cities. The survey will be conducted in order to be able to address qualitative aspects of the MAVEN project.

5.4 Traffic management requirements

This Roadmap has identified some questions for MAVEN: Who decides to make platooning happen? What is the role of the authorities and road operators? What influence does it have?

Traditional traffic management activities, performed by or under the governance of public authorities, have been strongly affected by a combination of technology developments and private initiatives, meaning that the traffic manager is no longer alone in managing the roads and guiding vehicles. The growth and widescale adoption of traveller information and navigation services is increasing the influence of the private sector on the performance of the mobility system and it impacts on public policies. This shift of influence from public to private will grow further with increasing levels of automation in vehicles, where manoeuvring decision making on the roads will transition from the driver (regulated by public rules) to vehicle algorithms, developed and governed by private automotive industry.

Unless a strong publicly regulated mobility system will be implemented to face this situation, it is most likely that in the near future, a new concept of traffic management will be developed, which will be based on a public-private collaboration, where different operators jointly manage the traffic based on available resources and ruled by trade off commercial agreements.

By way of example, the MAVEN use case Platoon management could mean that the decision of creating, joining or leaving a platoon is a “negotiated decision” primarily between public authorities (collective interest) and the vehicle service provider (client preferences), and secondly (optionally) accepted/confirmed by the driver. The level of influence on the decision making can vary according to the context and situation. For instance, in situations of high impact on societal goals such as road safety or emergency events, the public authority could have more (or full) control on the decision making. In other regular situations, only affecting traffic efficiency for example, the service provider could have the freedom to decide.

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5.4.1 Organisational aspects: the role of the traffic manager in the future

Transport professionals[4], including traffic managers themselves, acknowledge the role of traffic management to deliver wider policies: it is no longer just about managing cars but about delivering accessibility. Traffic management is becoming a **strategic tool for delivering a whole range of transport policies**, and the ultimate goal of becoming a liveable city characterised by less congestion, better air quality and more walking and cycling.

It is expected that more and more operational decisions will be made by systems, however, these will be guided by policy. The focus of traffic management systems will still be on larger urban centres and cities, as smaller towns are less likely to need such complex systems.

The goals of road safety and efficiency will remain in the future but traffic managers will have different resources to achieve them:

- The traffic system will be composed of **a mixed network of intelligent nodes** (either vehicle or infrastructure-based). The overall traffic system will have greater intelligence, enabling it to better assess situations (due to sensors and digital infrastructure) and to decide autonomously on the manoeuvres and movements of vehicles against a set of pre-defined policies, regulations and individual preferences.
- **Policies will be defined from a societal/collective perspective** and can be also adjusted to specific local conditions or communities. Vehicle policies will take into consideration regulations and individual drivers/travellers' preferences. The traffic manager will need to be able to configure policies at the system level, but also negotiate and orchestrate the interaction between the policies and individual preferences of drivers embedded in the vehicle's mobility services.
- The future of traffic management may be moving towards stronger **public-private collaboration** where different operators jointly manage the traffic based on their own available resources and potential commercial trade off agreements. The traffic manager will nevertheless continuously monitor the performance of the traffic system (network) as well as the impact of each of the vehicles and travellers' services against its pre-defined policies, with the ability to intervene to "influence" the operation of those services if required.

The above scenario will most likely happen in the medium to larger cities initially where there are traffic management centres which smaller cities tend not to have.

[4] City traffic managers convened at the MAVEN stakeholder consultation workshop in Barcelona in November 2016.

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5.4.2 Operational aspects: the impacts of different mixes of vehicles on traffic patterns

The linking of two or more vehicles in convoy using connectivity technology and automated driving support systems is defined platooning. **Platooning may in general have impacts on traffic flow and emission**, and can be indicated by:

1. Reduction of the number of stops at traffic lights;
2. Reduction of control delay time;
3. Decrease of produced emission;
4. Reduction of the overall fuel consumption or
5. Better use of the capacity of the existing infrastructure.

Expected impacts of different mixes of vehicles on traffic patterns cover:

- Speed advice based on signal phase and timing information should be calculated to enable a vehicle or platoon to pass a signalised intersection in the most efficient manner. The **expected impacts are a smoother vehicle trajectory while passing a signalised intersection**, which reduces stops and emissions. In case of a stop the start delay is expected to decrease as the start of the green phase is known in advance. As the driving speeds and the signal phases and timing will be optimized synchronously, the delay times at the signalised intersection are expected to decrease.
- The vehicles should be distributed over the available lanes to make optimal use of the road capacity. **The expected impacts are a smoother vehicle trajectory and improved traffic flow, which reduces stops, emissions and delays.**
- Improved queue length estimation can be coupled with a better control strategy of the traffic lights. **The signal optimization will result in more accurate speed advice for GLOSA. This in turn will improve traffic flow and reduce emissions.**
- A **dynamic green wave for automated vehicles in close cooperation with GLOSA speed advice** with less impact on other traffic than traditional green wave systems should result in **less travel time and pollutant emissions**.
- **Improve controller performance** (reduced average delay and stops for all traffic) by using the new data and functionality. The resulting optimal signal plans and the proper management of automated vehicles will result **in less travel time and emissions**.
- A bidirectional exchange of information for negotiations using communications from infrastructure to vehicles and vice-versa will create the basis to optimize traffic management in the context of connected automated traffic at road intersections.

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- The detection and characterization of complementing non-cooperative road users (vulnerable road users, non-cooperative vehicles) will ensure continuity in the generation of safety and traffic efficiency by providing the basis to react to situations in which the presence of non-cooperative road users could disrupt the implementation of the MAVEN functionalities.

5.4.3 The effect of the MAVEN system in different traffic scenarios

Traffic management is typically focussed on reducing congestion, unnecessary delays and accidents. **Building new roads is not an option for most cities**, due to lack of space, financial constraints and the unwanted environmental impact of creating even more car journeys.

In the small city of Helmond (NL), traffic light optimisation through C-ITS showed a potential 20% increase of road capacity. Optimisation of the road network will remain a key focus in the coming decades, with the introduction of automated vehicles and in view of the fact that cities are increasingly reassigning road space to other modes (cyclists, public transport, pedestrians, etc.).

- Adoption of the MAVEN approach may offer **cities**:
  - Improved traffic flow and lower environmental impact while supporting growth;
  - Improved safety, lowering societal costs and increasing attractiveness to prospective residents
  - Increased network performance reducing the need for extra physical road infrastructure.
- **Public Transport** could also benefit from MAVEN style guidance prioritising their movement through the city road network and thus increase the attractiveness of public transport for users while lowering operational costs.
- Also, **heavy goods vehicles** could be handled as special road user types with a special level of priority. Better flow of heavy goods vehicles on main corridors through the city could improve network performance. On the other hand, lower priority for heavy goods vehicles on undesired routes could be an effective way to manage traffic flows according to the city’s mobility policy without the need of a costly enforcement.
- **Vehicle drivers and road users** will experience:
  - Improved quality of driving and fuel saving through enhanced traffic flow;
  - Improved comfort for individual drivers due to automated and more homogenous driving on urban corridors and

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  - Improved safety for drivers and other road users (e.g. VRUs) through enhanced sensor ranges built in to AVs.
- **Vehicle-makers will be able to provide new safety, efficiency and comfort functions** for their customers and enhance competitive advantage. Offering MAVEN-compliant services to customers will result in a better reputation as a provider of enhanced functions for safety and comfort to enjoy the time spent in a car.
- **Infrastructure service providers will enter a higher value business** compared to a classical hardware-oriented business and will be able to offer intelligent intersections as a service based on Service Level Agreement (SLA) in line with their policy objectives.

5.5 Operational traffic management requirements

MAVEN is developing automation functionality over the course of the initial project (and beyond). These functions will need to take into account a mixed traffic composition, including non-AVs as well as AVs with different capabilities and automation levels, and even different communication techniques. As the MAVEN consortium research progresses, all types of vehicles will be classified in a 'traffic hierarchy' built into the MAVEN approach. Critical to this will be the ability to share information between the vehicles and infrastructure so as to enhance the overall safety and efficiency of all participants on the road.

What happens in case of **system malfunction?** MAVEN targets at vehicle automation developments between SAE level 3 and 4. The developed message sets can be used for both levels. Nevertheless, the system behaviour will be different in both levels. An automation of SAE level 3 will simply try to get the driver back into the loop. A SAE level 4 vehicle will perform minimum risk manoeuvres on its own.

Nevertheless, the developed functions are including several safety measures, as not all system malfunctions need to result in the complete loss of the automation functionality.

More detailed information about system malfunctions, minimum risk states and targeted behaviour of AVs in a hierarchical traffic management can be found in the project deliverables of Research and Innovation Programme Horizon 2020 TransAID [11].

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6 MAVEN cities examples

The three case studies which were carried out by MAVEN in European cities illustrate different levels of city awareness and understanding of connected automated vehicles and vehicle-to-infrastructure technologies and how they could transform mobility within cities.

For each city we looked at their specific transition approach (see also Chapter 4.5), on which MAVEN use cases can apply to the local context and what steps are needed for implementation.

6.1 City of Helmond, the Netherlands

Helmond is a medium sized city in the south of the Netherlands, with a current population of around 90,000 inhabitants. Helmond is part of the Brainport area, one of the three most important economic areas in the country. Innovation is the key-word here and for Helmond the focus lies on innovation on the fields of automotive and mobility.

Helmond is home to the Automotive Campus, where over 35 companies work on innovative mobility solutions. With the Automotive Campus, Helmond presents itself as a knowledge and innovation centre for mobility solutions and as “City of Smart Mobility”.

Though a relatively small city Helmond receives international recognition for its ambitious goals and the realisation of innovative mobility solutions in the city. The Brainport region hosted the Intelligent Transport Systems ITS Europe 2019 Congress in June 2019, where the active role of Helmond as a Living Lab for ITS was showcased.

Figure 9: Impressions from the MAVEN live demo in Brainport at the ITS Europe 2019 Congress

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6.1.1 The starting point: a policy change

It all started when Helmond saw major traffic problems due to the growth of mobility in early 2000. Various studies have been started to find out how the city could overcome those traffic problems. These studies resulted in different solution directions: the expansion of physical road infrastructure or a totally different direction, namely choosing to manage traffic. Dynamic traffic management was on the rise in that period. The growth of mobility was difficult to facilitate and new infrastructure often led to an even greater growth of mobility.

The mere expansion of physical infrastructure would have entailed enormous costs and would not solve all traffic problems. Helmond had about 60 traffic control installations at its disposal, and so 60 potential traffic managers. Therefore at this time it was decided to invest in traffic management.

When traffic management was also embraced nationally, almost all traffic control installations in Helmond were converted to network control installations, partly with the help of subsidy programmes from the State and the Province. This was the first major step Helmond had taken. By realising the network controls, the traffic problems did not occur in the city and accessibility was guaranteed in recent years.

6.1.2 City of Smart Mobility

The leading role in dynamic traffic management has given Helmond the name "City of Smart Mobility". The municipal traffic policy is based on a smart approach to mobility, moreover Helmond has an important economic ambition with Smart Mobility. The automotive industry, which in the past was also located in Helmond, was revived. This is visible in recent years in the (inter)national driving role that this top technology region fulfils in the automotive field. As a result, the municipality has a driving role in the expansion of the home base, the Automotive Campus in Helmond. With its mobility policy, the municipality is making an extra contribution to smart mobility by profiling itself as a testing ground or “living lab” for new mobility techniques and solutions. This will give many of the innovative mobility developments their first application in Helmond and will enable important experiences to be gained.

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6.1.3 Living Lab projects

Helmond has made a deliberate choice to actively land smart mobility pilots and showcases. The city believes in the principle of learning by doing and is convinced that innovative developments can be taken one step further by actually testing them together with the business community and educational institutions.

Helmond was a partner in the FREILOT project [12] and its outcomes are implemented in the city today. Helmond must deal with a large volume of heavy goods vehicles on the main road through the city (3.000 trucks per day). This results in many stop-and-start manoeuvres, noise, emissions, and a negative impact on traffic efficiency. The city used FREILOT C-ITS for priority for trucks at intersections and speed and time-to green advice to drivers. The outcome of the pilot was 13% fuel savings, 13 % less CO_2 and better traffic throughput.

Figure 10: FREILOT fourteen equipped intersections in the urban zone. City of Helmond

After FREILOT, Helmond has been an active partner in the Compass4D project [13], with the aim of scaling up the results of FREILOT and making the transition towards large scale deployment of these C-ITS services easier.

Helmond plays an active role in many EU projects, which can be separated in two main groups:

1. **Contribution to large scale deployment of C-ITS**
   - **C-MobILE** aims to stimulate/push existing and new pilot sites towards large-scale, real-life C-ITS deployments interoperable across Europe;
   - **CAPITAL** aims is to design and deliver a collaborative capacity-building programme comprising training and further education for practitioners in the public and private sector in the field of C-ITS deployment;
   - **C-The Difference** pilot project assesses the impact of C-ITS services in a real life urban transport environment.

2. **Preparation for the introduction and deployment of Automated Vehicles**

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- **MAVEN** focuses on the cooperation between individual automated vehicles and an intelligent infrastructure specifically at signalised intersections and signalised corridors;
- **AUTOPILOT** brings together relevant knowledge and technology from the automotive and the Internet of Things value chains in order to develop Internet of Things-architectures and platforms which will bring Automated Driving towards a new dimension;
- **CoEXist** develops "AV-ready" transport models and road infrastructure for the coexistence of automated and conventional vehicles;
- **FABULOS** delivers a systemic proof-of-concept on autonomous last mile public transport as part of the urban areas' existing transport system, based on use of autonomous self-driving minibuses for transporting people.

Living Lab also means that the (traffic) systems must be up to date and can therefore involve extra investments, which of course is at odds with the use of public money. To avoid divestments, Helmond is therefore working hard to organise the tests in such a way that they can actually be implemented at a later stage. When the test took place with communication between roadside systems and vehicles and there was no standardisation yet about the way of communication, Helmond insisted that two ways (hybrid) of communication could be tested (Wifi-P and cellular).

6.1.4 MAVEN approach

Because of the previous steps Helmond had gone through the past years, the step for the MAVEN use cases was a small and logical step.

Traffic control requirements

In addition, Helmond is working on making their traffic controllers even more advanced because the choice was made in the Netherlands (by the "Better Benutten"- programme) to standardise all traffic controllers so that communication between roadside system and vehicles is possible.

Sensor requirements

Sensors are not the responsibility of the city of Helmond. Other partners (OEM's) contribute to the MAVEN project with these requirements. But Helmond is eager to learn if adjustments in the area of Helmond are necessary to enable these systems to function better.

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Communications requirements

In earlier projects Helmond had already forced to test/apply different communication protocols because standards had not yet been set. Therefore, investments in communication equipment could be a disinvestment. But it may require a small extra investment to implement different communication protocols now have to be implemented, but it also gives the possibility to test and test the different protocols in relation to each other.

Physical infrastructure requirements

Helmond has already good lane markings on its main roads and makes them available in a living lab. By participating in tests and pilots, it is also becoming clearer whether its network is adequate for the sensors and maps that are used or whether adjustments are necessary to the infrastructure to make driving with self-driving vehicles possible in the city.

6.1.5 Conclusion

For Helmond the added value of MAVEN is a clear connection between traffic management and AVs. This is exactly what Helmond is looking for: automated vehicles as part of a connected and sustainable mobility system, with a good balance between individual mobility needs and societal goals.

A full assessment of Helmond's awareness, readiness and implementation of automation ready measures is shown in Table 2. The CoEXist framework of city readiness has been used for this assessment, where each category has been graded on a 3-point scale from no progress though partial progress to ready for each stage.

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Table 2: Helmond awareness, readiness and implementation of automation ready measures. Source: MAVEN, 2019

Mobility Aspect	Automation Awareness	Planning for Automation Readiness	Implementation of Automation Ready Measures
Policy	✓	✓	✗
Infrastructure	✓	✓	Partial
Planning	✓	partial	✗
Capacity Building	✓	✓	✗
Traffic Management	✓	partial	✗

- **Policy** - In its mobility policy, Helmond is making an extra contribution to Smart Mobility by profiling itself as a testing ground or 'living lab' for new mobility techniques and solutions. New policy plans assign opportunities to CAV's and Smart mobility to contribute to the achievement of policy goals such as accessibility, traffic safety and environmental aspects.
- **Infrastructure** - Since embracing traffic management at the beginning of this century, Helmond has invested in state of the art traffic lights, implementing network control, and tested different communication protocols between roadside units and traffic. A great deal is also invested nationally through the "talking traffic" project, where government and businesses are jointly taking responsibility to improve the flow of traffic in urban areas using smart new technologies.
- **Planning** – By being a living lab Helmond is contributing in several of testing activities and research projects to get more awareness about automation. With this experiences Helmond implement successful solutions in their future plans so at the end they can be applied in the future.

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- **Capacity Building** – Because of the opportunities that are attributed to CAVs and smart mobility in being able to handle traffic more efficiently and, for example, being able to allocate more time to other modalities such as slow traffic, Helmond is taking part in tests in order to possibly apply this later.
- **Traffic Management** – Traffic and especially traffic management is pre-eminently something that needs to be developed in close collaboration with OEMs and educational institutions. When traffic and traffic managers can talk to each other and are aware of each other, the traffic system can deliver its full potential. This requires good data management and standardisation (in data exchange) and that is something that still requires a lot of attention. In the projects in which Helmond participated, it became clear that much still needs to be done by all parties.

6.2 Royal Borough of Greenwich, United Kingdom

Greenwich is one of 33 London Boroughs, and is situated south of the river Thames to the east of Central London. It is designated as one of London's "Growth Boroughs" and its current population of 255,000 is estimated to grow by 43% in the next 10 years.

6.2.1 City transport policy today

Longer term, major transport infrastructure schemes such as Crossrail and River Crossings are undertaken by Transport for London (TfL) as the regional lead, however the Borough is a primary stakeholder, consultee and contributor to the development of schemes and they form part of RBG's emerging draft Transport Strategy; this is designed to provide a framework which allows RBG to prioritise and promote the transportation investment required to meet a number of objectives, including the Borough's broader growth and poverty alleviation objectives.

RBG is responsible for producing a Local Implementation Plan for Transport (LIP). This document is written in conformity with the London Mayor's Transport Strategy (MTS) and Spatial Strategy (the London Plan), as well as with the Borough's own wider strategies, aims and aspirations.

The current Mayor of London consulted on a new MTS in 2017 and published a revised strategy in 2018, after which RBG produced a new LIP.

The LIP has a dual role. In the short term it looks at the priorities and deliverables which will be implemented in the next 3-year Spending Period, however it also acts as a sign-post to

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RBG's medium and long-term transport ambitions and concerns which will be quantified in the developing Transport Strategy.

The LIP programme is funded by the Mayor via Transport for London (TfL).

In addition to the LIP and its spending plans RBG has adopted Cycling and Parking Strategies, and annually produces a Road Safety Plan and Child Road Safety Audit (which help prioritise the schemes delivered through the LIP programme).

RBG's primary land use policy, encapsulated in the Local Plan produced by the local planning authority, needs to be in general conformity with the London Plan, and the policies guide decisions on planning applications.

The Local Plan provides greater detail, evidence and policies than are contained within the Opportunity Area Planning Frameworks (OAPFs) and has greater material weight in the determination of planning applications. Royal Greenwich's Local Plan consists of:

- **The Core Strategy** – the key strategic planning document for the Royal Borough of Greenwich;
- **A policies map** – sets out the policies and site allocations in Royal Greenwich; and
- **The site allocations plan** – identifies particular sites in Royal Greenwich for specific uses such as housing or education.

6.2.2 Traffic management today

The majority of the road network is under the control of RBG. Approximately 5% of the network – main arterial routes through the borough - are composed of the TfL managed Transport for London Road Network (TLRN).

Arterial and primary routes are also managed by RBG – the Strategic Road Network (SRN) – however all works on this part of the network must be completed in consultation with TfL. TfL is also responsible for all traffic signals and their timings in London whether on the TLRN or borough-controlled roads.

RBG's Traffic Management team are also responsible for co-ordinating and licencing all street works. Additionally, the Borough is tasked with managing and maintaining highways assets (including street furniture, signage and street lighting as well as delivering the Winter Service Plan.)

Existing transport networks shape current travel patterns in RBG. TfL's Public Transport Accessibility Level (PTAL) measure provides a detailed and accurate measure of the

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accessibility of an area to the public transport network taking into account walk access time and service availability.

The PTAL scores for the borough are shown below in figure 11. They indicate that although Woolwich town centre (and to a certain extent Greenwich town centre) has very good access to public transport, accessibility is poor for large parts of the rest of the borough.

These poor levels of public transport accessibility discourage the use of public transport and contribute to higher levels of car use as discussed in the previous section. Private vehicle use accounts for roughly a quarter of trips by out-commuters and likely indicates those seeking to travel to locations immediately north and south of the borough, which are less well served by Underground and rail links.

In contrast, the results for those commuting to the Borough for work show a dependence upon private vehicles, which is likely to be due to a combination of factors associated with the origins of individuals' commutes but could include low accessibility to public transport and shift-working patterns of employees. The highest number of in-commuters to Greenwich live in Bexley. Sixty-six percent of these individuals drive to work whilst the most popular form of public transport is the bus (18%).

The promotion of active and sustainable travel, the reduction of single vehicle occupancy car journeys, and addressing congestion and road-based emissions remain priorities for the Council.

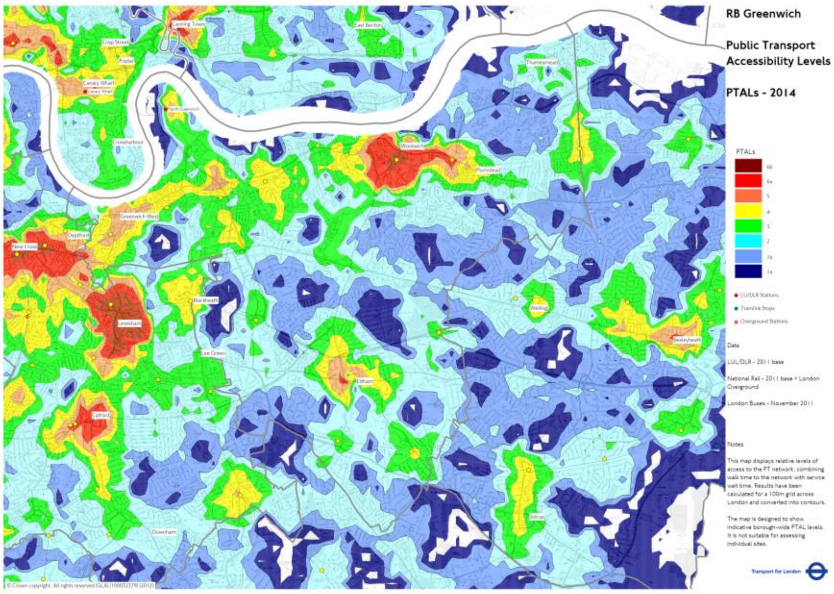

Figure 11: Royal Borough of Greenwich Public Transport Accessibility Levels -PTAL (2014)

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6.2.3 *Smart Cities and Autonomous Vehicles Projects*

DG Cities, on behalf of the Royal Borough of Greenwich, is undertaking multiple projects within the smart cities and autonomous vehicles space. These efforts align with tackling some of the challenges outlined above, particularly reducing private vehicle ownership, reducing single occupancy journeys and promoting walking, cycling and the use of public transport. A sample of these projects is listed below:

- **GATEway**. This project is focussed on understanding the human factors around specific AV applications, including ride sharing in driverless pods, valet parking and last mile deliveries to individuals. The learnings so far are significant, highlighting the following benefits and barriers:
  - **Technology readiness** - a significant amount of work has still to be done to ensure truly safe and reliable driverless vehicles. The market is still nascent and there is a lack of standardisation requiring bespoke integration of sensors, AI and vehicles.
  - **Public engagement and acceptance** have been very high and positive. This is potentially due to the novelty of AVs at the moment but does give significant confidence that there is demand for AVs from the public at large.
  - It has also informed the **timescales** over which we can expect AVs to penetrate the market, with realistic estimates looking towards 2040 or later for a majority AV vehicle fleet.
- **MERGE**. This project is focussed on exploring autonomous ride-sharing models that increase accessibility within areas poorly served by public transport as well as giving users preferences for who they share rides with to increase their confidence in any potential future services.
- **AV Testbed (the Smart Mobility Living Lab: London)**. This is a significant project, one of 2 real world AV test beds in the UK. The Innovate UK £20m funded build is completed in 2020 after which it operates (jointly by dg:cities and the Transport Research Lab [TRL] as SMLL Ltd) that will, with partners, create a physical, on-road testbed for AVs on 24kms of Greenwich's public highway and in the Queen Elizabeth Olympic Park in East London. It is one of 4 testbeds in the UK. Communications and IT infrastructure will be deployed to enable C-ITS and MAVEN style applications as well as providing a framework for testing and validating AVs, AI and Sensor technology so that it can be certified as safe for the UK roads.

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These investments place Greenwich as a forerunner in both smart cities and AV applications and make Greenwich an ideal partner for transitioning MAVEN from concept to a commercial reality.

6.2.4 Conclusion

MAVEN provides the framework for the borough to be able to increase the efficiency of its current road network, alongside other C-ITS applications, and therefore the design and ultimate deployment process for MAVEN is of key importance to the project as a whole.

A full assessment of Greenwich's awareness, readiness and implementation of automation ready measures is shown in Table 3. The CoEXist framework of city readiness has been used for this assessment, where each category has been graded on a 3-point scale from no progress though partial progress to ready for each stage.

Table 3: Greenwich awareness, readiness and implementation of automation ready measures. Source: MAVEN, 2019

Mobility Aspect	Automation Awareness	Planning for Automation Readiness	Implementation of Automation Ready Measures
Policy	✓	Partial	✗
Infrastructure	✓	✓	Partial
Planning	✓	Partial	✗
Capacity Building	✓	✓	✗
Traffic Management	Partial	✗	✗

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Through investment in multiple autonomy-related projects, Greenwich has been building a body of knowledge and capability around connected autonomous vehicles.

- **Policy** - CAVs are seen as an opportunity area for cities that could transform accessibility throughout the city, for all residents and users. It has been recognised that the market is driving towards a Mobility as a Service model and that through previous experiences, particularly in the area of taxis and private hire, have galvanised cities to be more proactive in their involvement in technological and market developments.
- **Infrastructure** - Investment in the Smart Mobility Living Lab, which will operate within Greenwich, is enabling the borough to be at the forefront of testing and validating CAVs and MaaS related services. The infrastructure includes fixed and mobile telecommunications, extensive monitoring devices and V2X communications devices to allow for the testing and implementation of MAVEN style use cases.
- **Planning** - Greenwich citizens have been involved in multiple CAV related trials and continue to be to the benefit of existing and future projects. It is imperative to involve residents and customers in these trials and projects to ensure that technologies and services are developed, first and foremost, with people in mind. Cursory modelling work has taken place to understand specific areas, such as logistics and ride sharing, but wide scale modelling has not yet taken place
- **Capacity Building** - Greenwich created DG Cities, it's innovation company, in 2015. The goal in doing this was to build both organisational capacity and domain knowledge in the smart cities and smart mobility areas.
- **Traffic Management** - Traffic Management in London is predominantly the responsibility of Transport for London, whose road network extends across all London boroughs. Greenwich retains traffic management responsibility outside of the TfL network and, like many other London boroughs, has a relatively small and focussed team of traffic managers.

6.3 City of Braunschweig, Germany

Braunschweig is a medium sized city (approx. 250.000 inhabitants) located in Niedersachsen in Germany. MAVEN project partner DLR (the German Aerospace Centre) has a large research facility in Braunschweig and one of the MAVEN test locations is situated in Braunschweig.

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6.3.1 Transport research

In Braunschweig there are no specific transport or mobility challenges, other than the "regular" traffic issues in cities of this size, such as a certain level of congestion during rush hours. The city has inherited a "car-friendly" physical infrastructure, which has contributed to the avoidance of major congestion issues until now.

The public transport system is based on two main pillars: a high-quality tram system especially connecting high demand residential areas with the city centre and a bus system aiming at connecting the surrounding villages and outside districts of Braunschweig with the city centre and with the tram system.

The context for cycling is quite positive (e.g. no hills) and this is one of the reasons for a relatively (for German cities) high share of cycling in the modal split (according to surveys done between 2010 and 2018 the modal split for cycling ranges between 20 and 25 %).

6.3.2 Strategy

The City of Braunschweig currently does not have an official mobility plan in place. The main priority for the next coming years is the extension of the tram network (currently approximately 39 km) by approximately 18 km until 2030.

The city is showing an interest in developments related to automated vehicles, however at this early stage it holds the view that it is not yet appropriate to invest public money in preparing for automated vehicles since it is still very uncertain which standards and regulations will apply for automated vehicles and for traffic infrastructure. Furthermore, the impact, benefits, standards, regulations and responsibilities should be made clearer before public money is spent.

A real positive impact of AVs can be expected in Braunschweig from a combination of transport electrification, automation and use of shared vehicles. At this stage there are no plans to deploy for example automated shuttles to replace buses, as the main priority for public transport currently lies with extending the tram system. Also, legislation on federal level could be a serious deployment barrier for AVs. It is not expected that the German federal government will allow massive AV testing and deployment in the very near future.

With a large DLR research facility and DLR test sites in Braunschweig, the city of Braunschweig as such is a living lab for ITS – innovation. From an economic point-of-view, this could be considered as an important asset for the city.

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6.3.3 Traffic Management

Thirteen years ago, the city of Braunschweig outsourced the municipal traffic management to the service provider company Bellis, which has been founded specifically for this purpose as a cooperation between Siemens and the local utility company, BS|Energy. Hence Braunschweig brought Traffic Management as a Service into practice already many years ago. When outsourcing, it is important for a city to be able to monitor the services and performance based on clear KPI's. Possible vendor-lock-in can become a major barrier for innovation if effective counter-measures are not clearly agreed upon in the contract. From a strategic point-of-view, outsourcing also means less involvement of the city authority in traffic management innovation and strategy.

Furthermore by signing a 10-,15- or 20-year contract, cities might lose their ability to adapt to changing requirements or implement new possibilities regarding traffic management since the services to be carried out by the contractor are defined at the beginning of the contract period are legally binding and can barely be changed during the run-time of the contract. These aspects should be carefully considered by other cities when planning for outsourcing traffic management.

6.3.4 City of Braunschweig and MAVEN

Partly due to outsourced traffic management, the city of Braunschweig will in the short term not be able to make real use of the MAVEN findings. For example, adaptation of the physical and/or digital infrastructure to prepare for the MAVEN scenarios have to be implemented by Bellis and will imply a unbudgeted additional cost for the city. Braunschweig recommends the MAVEN project to liaise with FGSV, the Road and Transportation Research Association (www.fgsv.de) which serves in Germany as a kind of standardisation body for traffic management for cities and many other topics regarding roads and transportation in general. Through updated FGSV recommendations, a large city base in Germany could be reached to prepare for MAVEN applications and services. Furthermore, Braunschweig would be very interested to learn more about a "cars adjust to infrastructure approach": if AVs could adapt to all possible infrastructural environments, no public money would be needed to adapt the infrastructure. So far however only some US-based suppliers seem to follow this strategy.

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6.3.5 Projects

An example of some projects taking place in the area of Braunschweig are listed below:

Project	Description
Testbed Lower Saxony	The Testbed Lower Saxony is a large-scale research platform for the development and evaluation of connected and automated mobility. This covers the entire tool chain from simulation to real testing. Tests can be carried out on country roads and motorways or directly in the city. It is extending the AIM test site located in the city centre of Braunschweig.
MENDEL	The German research project MENDEL aims to minimize the total operating costs of electrically powered bus fleets. This includes a cost reduction for the construction and operation of charging infrastructures by minimising the load on the power grid, as well as a reduction of the energy consumption of vehicles in operation. The project combines the two fields of Smart Grids and Intelligent Transportation Systems (ITS) to a prototypical system concept.
SIRENE	The project SIRENE (Secure and Intelligent Road Emergency Network) aims at the optimization and protection of the routing for emergency vehicles. Traffic predictions of cooperative infrastructure implemented in AIM are used for this purpose in a centralized (by using back-ends) and distributed (by using V2X communication) way.
DK4.0	The aim of DK 4.0 ("Digitaler Knoten", "digital pivot") is to realise automated driving (SAE level 4) at urban intersections considering mixed traffic situations including automated as well as non-automated vehicles, cyclist and pedestrians.
TransAID	The project TransAID (Transition Areas for Infrastructure-Assisted Driving) aims at developing traffic management solutions for automated vehicles which are in the need of performing transitions of control. A subset of the measures is going to be implemented on public roads in Braunschweig.

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The projects MAVEN and AUTOPILOT are also active in Braunschweig but have been introduced in the description of Helmond already.

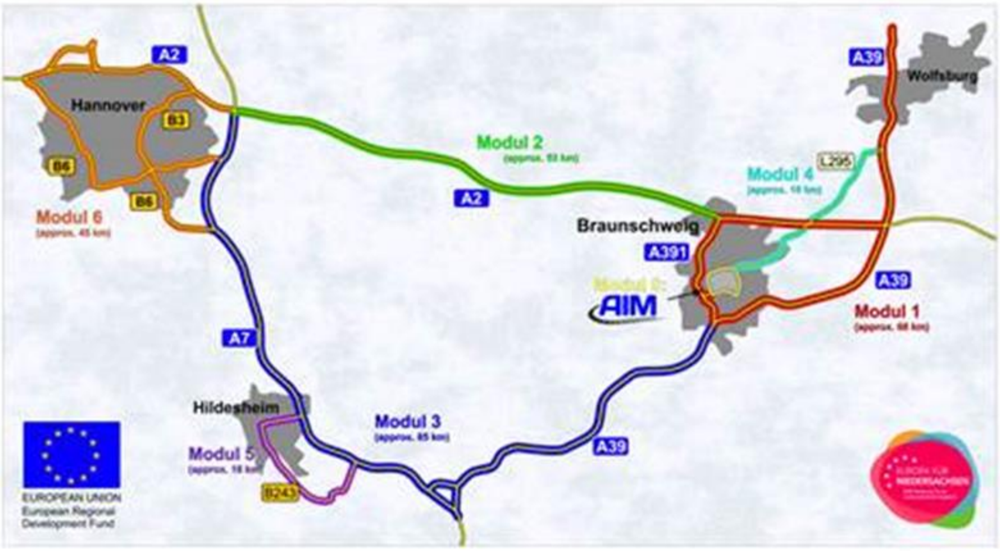

Figure 12: Testbed Lower Saxony, and the linking to AIM test site in Braunschweig.

6.3.6 Conclusion

Braunschweig is very active in the field of research of new technologies in the domain of transportation. Nevertheless, the field of traffic management is currently very much limited to this kind of activity, related to the projects and the project durations. In terms of sustainable traffic management for all, the city of Braunschweig is facing similar issues as other cities of that size, and therefore still standing at the beginning, although a lot of infrastructure is already in the field.

A full assessment of Braunschweig's awareness, readiness and implementation of automation ready measures is shown in Table 4. The CoEXist framework of city readiness has been used for this assessment, where each category has been graded on a 3-point scale from no progress though partial progress to ready for each stage.

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Table 4: Braunschweig awareness, readiness and implementation of automation ready measures. Source: MAVEN, 2019

Mobility Aspect	Automation Awareness	Planning for Automation Readiness	Implementation of Automation Ready Measures
Policy	Partial	Partial	✗
Infrastructure	✓	✓	Partial
Planning	✓	Partial	✗
Capacity Building	✓	✓	✓
Traffic Management	Partial	Partial	✗

In Braunschweig, all traffic management aspects and the infrastructure service are currently privatised and therefore only a limited part of the city's development activities. On the other hand, several research institutes are investing in the infrastructure creating awareness about future automation aspects which are also partly put into real life and demonstrated in the city. The table above therefore stands for the mixed overall position of the city, including also the private company's and research institutes' activities.

- **Policy** - CAVs are seen as an opportunity area by the research institutes and the city itself. The research institutes are also very active in putting the overall mobility aspects, like the Mobility as a Service model, into real life, although this is done on a prototypic level only.
- **Infrastructure** – Starting in 2014 with the Application Platform for Intelligent Mobility (AIM) [15], the inner city's ring road and other heavily used areas of the road network have been equipped with V2X communication hardware. In addition, some intersections are also equipped with cameras able to track and predict road users' movements online, leading to support functions for automated vehicles. The whole

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communication system is running most of the time; several other implementations are currently implemented or frequently adapted to current research projects. Braunschweig is also a major part of the currently built Test field Lower Saxony [16], where the communication and camera equipment of AIM is extended to interurban roads and highways.

- **Planning** – Especially the research institutes have a strong interest to involve citizens in CAV related trials to estimate the road user's needs of the future. This research is also shared with the City of Braunschweig and discussed to allow planning of future activities in the light of Mobility as a Service.
- **Capacity Building** – The City of Braunschweig is proud to be one of the most important areas for research in Germany. The research institutes dealing with ground based traffic are growing every year, ensuring that Braunschweig is staying a major player in the fields of smart cities and smart mobility.
- **Traffic Management** - Traffic Management is currently done by a private company in Braunschweig. Although vehicle automation has been recognised, it does not yet play a major role in this area. On the other hand, the research institutes are already investigating different new approaches of traffic management in Braunschweig, which are frequently (and prototypically) brought into service on different road corridors in the city.

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7 Conclusions and steps to be taken

It is clear that the world of transport and traffic is on the verge of some major changes. The advance of Intelligent Transport Systems challenges everybody involved in this world to look again at the way transport and traffic are organised and managed. The MAVEN project focuses on traffic management at signalised intersections along urban corridors, but the conclusions and recommendations can be valuable for most other traffic environments and certainly the general recommendations can give guidance in environments where cooperative ITS systems will be introduced.

This Roadmap is presented at the end of the MAVEN project in August 2019. Many of the conclusions and recommendations presented in earlier versions of this document may have changed or been influenced by the experiences during the course of the project. Some others, however, and mainly the more general ones, are based on the simple fact that change is going to come and that adaptation to the changing environment is needed. In the early phases of a development it is difficult to decide on concrete steps that must be taken to cope with the consequences of such a development. Certainly, where investments in equipment and personnel are concerned it is easy to make wrong decisions when the consequences of decisions cannot yet be understood in detail. On the other hand, waiting until it is clear what developments are going to bring could be a loss of time and will cause others to move faster and reap the economic benefits of developments before European stakeholders do. There are initiatives that policy-makers, road-authorities, standards-development organisations and other stakeholders can take, even at present, to be better prepared for the changes that are going to come.

Many of the issues discussed in this document do not have a final solution or conclusion. It is not always possible to foresee exactly what the future will bring. In January 2007, when the first iPhone was presented very few people would have believed the all-important role smart phones play in our lives today, hardly 10 years later. Therefore, the most important role of this document is not to give detailed answers to questions, but to create awareness of the changes that are going to come, to indicate where adaptations are needed and to start discussions on how to adapt to these changes.

7.1 General

Awareness and education: Whether or not the introduction of new technology is going to be a success depends strongly on the acceptance of the stakeholders at all levels. And the acceptance of stakeholders depends strongly on whether or not they are well informed about the changes and their consequences. Every change meets with hesitation and resistance, but

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a well-organised information campaign can at least minimise hesitation and resistance. This goes for stakeholders at all levels. Policy makers, traffic managers, the police force and the general public. Information campaigns should be set up targeting each of these particular groups of stakeholders.

Standards and laws traditionally follow technological developments. The consequence is often that technology ready to be introduced on the market cannot be introduced because existing standards and laws prohibit the introduction. In 2016 all EU Member States endorsed the Declaration of Amsterdam[5]. Jointly with the European automotive industry the European Union will move to clear the way for connected and automated driving in 2019. If successful this would clear the way as far as laws are concerned. It is important for the success of the MAVEN system to investigate what standards are being used in other C-ITS developments and to coordinate in order to be certain that MAVEN systems can be integrated with other CITS systems.

7.2 Steps to be taken regarding infrastructural requirements

MAVEN is developing solutions for managing level 4 highly automated vehicles at (urban) signalised intersections, including algorithms for infrastructure-initiated guidance to adjust the trajectory and manoeuvring policies of automated vehicles, while the infrastructure dynamically adapts the traffic light timing of signalised intersections based on the anticipated vehicle arrival pattern.

Before looking into infrastructure requirements, it is important to acknowledge that many of the MAVEN use cases have a large vehicle-component, therefore public authorities and infrastructure technology alone have limited influence. Nevertheless, for the use cases Speed Change Advisory, Lane change advisory, Signal optimisation and Detect non-cooperative road users, some progress can be made already to mature the infrastructure, which is also of benefit to non-automated but connected and cooperative mobility applications.

Requirements to enable signalised intersections to operate MAVEN use cases include: a digital infrastructure that gives access to signal phase and timing and topology data; roadside sensors for the detection of different traffic participants; communication technologies and computational resources are present, and UTC systems are upgraded with sophisticated I2V algorithms. Although applied to signalised intersection here, this sequence of access to data –

[5] The Declaration of Amsterdam on Cooperation in the field of connected and automated driving was signed by the EU Members States under the Dutch Presidency in April 2016. The declaration establishes shared objectives, a joint agenda and proposes actions for both Member States and the European Commission.

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enabling data collection – enabling exchange of information – adding intelligence, is one that is transferable to other contexts and domains.

7.3 Steps to be taken regarding transport policy

Since automated vehicles have the potential to significantly impact and change how people travel in the broadest sense, authorities (local as well as national as well as at a European level) should reconsider existing mobility plans and think about the consequences of the introduction of C-ITS on issues as the environment, modal split, land use, priorities for special category road users, etc. Based on their particular situation (in megacities the effect of the introduction of C-ITS may be strongly different from the effect in smaller cities and villages) a short term and long-term plan could be made: the short-term plan with concrete actions and the long-term plan with considerations and studies.

At present, the complexity of taking part in our hectic (urban) traffic can be a great challenge for special category road users, like vulnerable road users (the disabled, the very young and very old, cyclists), emergency vehicles and even logistics vehicles and public transport vehicles. C-ITS technology enables traffic management to take the safety and comfort of such road users in consideration far better than presently is possible. Emergency vehicles and public transport vehicles can be given preference at intersections, for instance by managing the green time when such vehicles are detected or are part of an approaching platoon. Vulnerable road users do not have to make instant decisions, because the system (infrastructure and vehicle) will guide them and will increasingly make decisions for them.

7.4 Steps to be taken regarding traffic management

Traffic managers are the people who are going to be in the front line when the MAVEN system is introduced. It is therefore essential that they have knowledge about all aspects of C-ITS. In many cities, C-ITS is not an area of interest yet, which may be attributed to a low level of awareness. Short-term courses and information material may be helpful and will soon become available through the CAPITAL project [17]. The aim of the CAPITAL project is to design and deliver a collaborative capacity-building programme (comprising of training and further education) for practitioners in the public and private sector in the field of (Cooperative) ITS deployment.

A very important issue for traffic management in the transition period towards a world where C-ITS is common is co-existence. During the transition period automated vehicles will co-exist

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with non-automated ones. The interactions between automated and non-automated vehicles should be studied as a part of the education of traffic managers.

7.5 Ongoing and future research and innovation activities

Whereas MAVEN has come to an end August 2019, a number of other European co-funded projects in the field of vehicle and road automation are still running throughout 2020.

CAPITAL, Collaborative cApacity Programme on ITS Training-educAtion and Liaison (1.10.2016 – 30.09.2019 www.capital-project.its-elearning.eu) is delivering a collaborative capacity-building programme (comprising of training and further education) for practitioners in the public and private sector in the field of (Cooperative) ITS deployment.

CoExist (01.05.2017 - 30.04.2020 http://www.h2020-coexist.eu) is looking at the transition phase during which automated and conventional vehicles will co-exist on urban roads. Through a cross-disciplinary approach and the engagement of relevant stakeholders, CoEXist is finalising an automation-ready framework for road authorities and is developing traffic simulation tools.

The **INFRAMIX** project (01.06.2017 - 01.05.2020 https://www.inframix.eu/) is looking at physical and digital interventions to prepare the road infrastructure for the introduction of automated vehicles.

The **European ITS Platform (EU-EIP)** (https://eip.its-platform.eu/) facilitates the establishment of a commonly understood state of the art and promoting the actual take-up of EU specifications, guidelines, best practices and/or methodologies in ITS. In particular, Sub-Activity 4.2 on Facilitating automated driving is preparing road authorities and operators to make decisions on facilitating automated driving and automating their own core business. The project is drafting a road map and action plan, focusing on the needs of road to facilitate automated driving on the TEN road network.

TransAID(01.09.2017 - 31.08.2020 https://www.transaid.eu) is developing and demonstrating traffic management procedures and protocols to enable the smooth coexistence of automated, connected and conventional vehicles, especially at “Transition Areas” on the roads where the level of automation is changing to cope with the road conditions. TransAID is producing a set of guidelines and a roadmap defining activities and upgrades of road infrastructure in the upcoming fifteen years.

An exhaustive list of ongoing and past projects can be viewed on the CARTRE-Coordination of Automated Road Transport Deployment for Europe website at https://connectedautomateddriving.eu/cad-knowledge-base/

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