D8.3

Guideline and Roadmap

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■ PU: Public

□ RE: Restricted to a group specified by the consortium (including the Commission Services)

□ CO: Confidential, only for members of the consortium (including the Commission Services)

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Executive Summary

The TransAID project defines, develops, and evaluates traffic management measures based on C-ITS equipped road infrastructure to eliminate or mitigate the negative effects of Transition of Control (ToC) along Transition Areas (TAs) in future mixed traffic scenarios where automated, cooperative, and conventional vehicles will coexist.

This document is written at the end of the project when the results are known, and stakeholder consultations are finished. Considering the results, which are summarised in section 2 based on the work of TransAID deliverable D8.2 and feedback gathered from stakeholders, as reported in TransAID deliverable D8.1, a guideline and roadmap are provided.

Many other initiatives in the field of Cooperative Connected and Automated Mobility (CCAM) also reported roadmaps, guidelines and recommendations (see section 3). These touch upon many aspects: vehicle type approval, infrastructure design, traffic laws, ensuring safe automated operation, driver education, liability, road and vehicle maintenance, traffic and incident management, reducing emissions, etc.

To prevent duplication and actually contribute to what is already known, TransAID decided to build upon the work of MANTRA (Amelink, et al., 2020) and EU EIP (Kulmala, et al., 2020). What sets their reports apart from the others is the concrete list of actions and recommendations that they include. Based on workshops with road authorities and road operators both projects produced an extensive list of actions and recommendations that affect the core business of road authorities and other stakeholders. From those lists, the actions and recommendations most relevant to the findings and results of TransAID are reflected upon in section 4. Using the lists of actions provided in the introductions of the subsections of that section, it can be used as a catalogue to lookup TransAID's position on the given action / topic.

The most notable actions and/or recommendations are:

- In general, we recommend the CCAM community to further explore the services proposed by TransAID. All services have shown potential through the positive results of the studied use cases (see section 2). We foresee that TAs will be there for long time, since for the coming decades automated driving (AD) will have its limitations. Without measures (connected) automated vehicles (C)AVs will disrupt traffic flows in TAs. It is thus recommended to prevent, manage or distribute ToC events. TransAID has simulated numerous use cases in great detail and demonstrated feasibility on test tracks and open roads. The next step should be additional pilots in the real world.
- Introduce and define safe spots / safe harbours. Our simulations have shown that it is beneficial for throughput, safety and emissions when CAVs have a space to safely stop outside traffic in case they have to perform a Minimum Risk Manoeuvre (MRM). Which areas exactly can be used or defined as safe spots is a topic for future work, but many existing spaces such as emergency lanes and safe harbours can be used for those. It is recommended to expand on such spaces upstream of (possible) TAs.
- For road authorities / road operators it is recommended to enable communications around TAs via V2X or other technologies (possibly hybrid solutions). Being able to collect and provide information (including collective perception) and/or advices to CAVs has proven beneficial and indeed, necessary, in all use cases. Without communications, AVs are limited to their own sensor boundaries and onboard data. Several use cases have shown that additional information can support CAVs in their planning and in some cases even is needed when common sense

dictates vehicles should bend traffic laws to overcome the situation (e.g., UC1.1, UC1.3, UC2.3 and UC4.2).

- More specifically, in the domain of communication, the concept of cooperative manoeuvring has shown much potential. The Manoeuvre Coordination Service (MCS) enables vehicles to align their movements, which facilitates smoother lane changes and for example more efficient merging in case of on-ramps. In addition, the MCS enables infrastructure to send lane change advice to CAVs which helps to allocate vehicles to certain lanes upstream in preparation of incidents or road works and/or lower the density on the right lane around on-ramps (to facilitate merging traffic). It is therefore recommended, especially to OEMs, road authorities/operators and standardisation bodies to further test and develop the MCS.
- In addition to communicating with equipped vehicles, our studies have shown that communications with unequipped vehicles can be beneficial as well. It could be very valuable if OEMs communicate (using, e.g., external LEDs) the currently driven automation performance / capabilities also to surrounding vehicles, especially in case of ToCs and MRMs. This could improve the situation awareness of drivers in the vicinity and therefore reduce safety critical situations. However, they would need to study the balance between the degree of distraction to surrounding vehicles / drivers vs. the added information (i.e., usefulness vs. information overload). It is recommended to continue pilots and draft specifications in this area.
- Removing the driver from the equation in case of AD means that all information must be digital and reasoning must be automated. To that end, it is essential that more data is shared between OEMs and road authorities/operators. This is true for many aspects such as the location and characteristics of TAs, general and detailed (microscopic) traffic information, traffic management plans / scenarios, and also regarding traffic laws and regulations. Standards, protocols and (governing) frameworks need to be defined to facilitate such sharing of information. There are already initiatives dealing with these topics, and we can only encourage continuation of such developments.
- To facilitate the sharing of data, consolidate knowledge and information, and overcome barriers such as intellectual property and trust, we recommend the introduction of (a) intermediary service(s) which can act as a trusted third party towards OEMs and road authorities. That service can collect and match information from both parties to identify and return TAs. In addition, it can match the capabilities of both OEMs and infrastructure to align measures around TAs with those capabilities. See section 2.6 for more detail.
- Finally, to support the above, it is recommended to explore and refine the concepts of the Operational Design Domain (ODD) and Infrastructure Support Levels for Automated Driving (ISAD). During virtually all stakeholder events, these concepts had support from participants, although OEMs are understandably hesitant to share ODD information because of intellectual property, and also technical challenges in the definition. Recent calls for proposals, such as CEDR 2020, show that at least road authorities recognise the potential of the ODD and ISAD concepts.

1 Introduction

In the following sections, we first give a concise overview of the TransAID project, then highlight the purpose of this document, and finally present its structure.

1.1 About TransAID

As the introduction of automated vehicles becomes feasible, even in urban areas, it will be necessary to investigate their impacts on traffic safety and efficiency. This is particularly true during the early stages of market introduction, where automated vehicles of all SAE levels, connected vehicles (able to communicate via V2X) and conventional vehicles will share the same roads with varying penetration rates.

There will be areas and situations on the roads where high automation can be granted, and others where it is not allowed or not possible due to various reasons (missing sensor inputs, highly complex situations, etc). As a consequence, there will be areas where many automated vehicles will need to change their level of automation to adopt more conservative operations or even give the control back to manual driving (Transition of Control, ToC in short). We refer to these areas as “Transition Areas” (TAs).

It can be expected that especially at TAs the simultaneous presence of automated, connected, and conventional vehicles will be challenging and possibly negatively affect safety and traffic efficiency. To cope with these challenges, TransAID develops and demonstrates traffic management procedures and protocols to prevent or mitigate the negative effects of ToC at TAs, hence enabling smooth coexistence between different types of automated and non-automated vehicles.,. A hierarchical approach is followed where control actions are implemented at different layers including centralised traffic management, infrastructure, and vehicles.

First, simulations are performed to find optimal infrastructure-assisted management solutions to control connected, automated, and conventional vehicles at TAs, taking into account traffic safety and efficiency metrics. Then, communication protocols for the cooperation between connected / automated vehicles and the road infrastructure are developed. Measures to detect and inform conventional vehicles are also addressed. The most promising solutions are then implemented as real world prototypes and demonstrated under real urban conditions. Finally, guidelines for enabling the TransAID vision on advanced infrastructure-assisted driving are formulated. These guidelines also include a roadmap defining activities and needed upgrades of road infrastructure. This document focusses on those guidelines and roadmap. A more detailed description of the TransAID project and its results can be found in section 2.

Iterative project approach

TransAID performed its development and testing in two project iterations. Each project iteration lasted half of the total project duration. During the first project iteration, the focus was placed on studying ToCs and Minimum Risk Manoeuvres (MRMs) using simplified scenarios. During the second project iteration, the experience accumulated during the first project iteration was used to refine / tune the driver models and vehicle automation functions, and enhance / extend the proposed mitigating measures.

1.2 Purpose of this document

This document provides a ‘how-to’ guideline for road authorities and/or service providers for dealing with automated driving in the urban environment in general and in TAs specifically. A roadmap for the coming 20 years is included for concrete required activities and possible road infrastructure modifications that local authorities can undertake, to facilitate the introduction of automated driving.

The roadmap includes recommendations steps to be taken by policy-makers, OEM's, infrastructure systems providers, standards-development organisations among others. Technical, political, societal, institutional and organisational aspects are considered within the scope of the TransAID project.

1.3 Structure of this document

Following the introduction above, section 2 provides a more elaborate overview of the TransAID project and its results. This provides the reader with the necessary background to interpret the recommended actions and considerations presented in section 4.

Section 3 provides an overview of other important roadmaps from recent initiatives, especially MANTRA (Amelink, et al., 2020) and EU EIP (Kulmala, et al., 2020) which form the starting point for section 4. A full consolidated list of actions and recommendations from those two initiatives is provided in Appendix B. From that list a selection is included in section 4 which is used to describe the actions and recommendations from TransAID as an extension of those of EU EIP and MANTRA.

1.4 Glossary

Abbreviation/Term	**Definition**
4G	Fourth generation standard of mobile communication
5G	Fifth generation standard of mobile communication
ACC	Adaptive Cruise Control
AD	Automated Driving
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving Systems
AI	Artificial Intelligence
ASAM	Association for Standardisation of Automation and Measuring Systems
AV	Automated Vehicle or Autonomous Vehicle
BIM	Building Information Modelling
CACC	Cooperative Adaptive Cruise Control
CAD	Connected Automated Driving or Cooperative Automated Driving
CAM	Cooperative Awareness Message
CAMP	Crash Avoidance Metrics Partnership
CAT	Connected and Automated Transport

CAV	Connected Automated Vehicle or Cooperative and Automated Vehicles
CCAM	Cooperative Connected and Automated Mobility
CCTV	Closed-Circuit Television
CEDR	Conference of European Directors of Roads
CEF	Connecting Europe Facility
C-ITS	Cooperative Intelligent Transport Systems
CPS	Collective Perception Service
CV	Cooperative Vehicle or Connected Vehicle
Dx.y	TransAID deliverable number x.y.
DENM	Decentralised Environmental Notification Message
DG	Directorate-General
DG RTD	Directorate-General for Research and Innovation
EC	European Commission
EIP	European ITS Platform
ERTRAC	European Road Transport Research Advisory Council
ETSI	European Telecommunication Standards Institute
EU	European Union
EV	Electric Vehicle
FP7	EU 7th Framework programme
GDPR	General Data Protection Regulation
h/w	hardware
H2020	EU Horizon 2020 programme
HCM	Highway Capacity Manual
HD	High Definition
HMI	Human Machine Interface
I2V	Infrastructure to Vehicle communication

ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
ISAD	Infrastructure Support Levels for Automated Driving
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LED	Light Emitting Diode
LOS	Level Of Service (from Highway Capacity Manual)
LTE	Long Term Evolution (cellular communication)
LV	Legacy Vehicle
MAPEM	Map Message
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
MRM	Minimum Risk Manoeuvre
NAP	National Access Point
NR	New Radio
NRA	National Road Authority
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PRT	Personal Rapid Transit
PT	Public Transport
RA	Road Authority
RO	Road Operator
RSI	Road Side Infrastructure
RSU	Road Side Unit
RTK	Real Time Kinematic

SAE	Society of Automotive Engineers
SP	Service Provider
SRIA	Strategic Research and Innovation Agenda
SRTI	Safety-Related Traffic Information
STF	Special Task Force
SUMP	Sustainable Urban Mobility Plan
TA	Transition Area
TEN	Trans-European Transport
TERAP	Trusted Electronic Regulations Access Points
TLC	Traffic Light Controller
TM	Traffic Management
TMC	Traffic Management Centre
TMS	Traffic Management System
ToC	Transition of Control
TR	Technical Report
TransAID	Transition Areas for Infrastructure-Assisted Driving
TRL	Technology Readiness Level
TS	Technical Specification
UC	Use Case
URL	Uniform Resource Locator
US DoT	United States Department of Transport
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2V	Vehicle to Vehicle
V2X	Vehicle to everything communication
VMS	Variable Message Sign

VR	Virtual Reality
VRU	Vulnerable Road User
WIM	Weigh-In-Motion
WP	Work Package

1.4.1 ODD

The Operational Design Domain (ODD) is a description of the specific operating conditions in which the AD system is designed to properly operate, including but not limited to roadway types, speed ranges, environmental conditions (weather, daytime / night time, etc.), prevailing traffic law and regulations, and other domain constraints.

1.4.2 ISAD

The environmental perception of AVs is limited by the range and capability of on-board sensors. Road infrastructure operators already employ numerous traffic and environmental sensors and provide information that can be perceived by AVs. In order to classify and harmonise the capabilities of a road infrastructure to support and guide AVs, INFRAMIX[1] has proposed a simple classification scheme (see Figure 1), similar to SAE levels for the AV capabilities (Manganiaris, 2019; Amditis, 2019). These levels can be assigned to parts of the network in order to give AVs and their operators guidance on the “readiness” of the road network for the coming highway automation era.

Infrastructure support levels are meant to describe road or highway sections rather than whole road networks. This reflects common practice of infrastructure deployment: Traffic control systems (sensors and variable message signs (VMS)) are usually deployed on motorway sections where traffic often reaches the capacity limit (e.g., in metropolitan areas), whereas other motorway sections need no fixed installations of traffic control systems because traffic flow is rarely disrupted. If a complex intersection is covered by dedicated traffic sensors, traffic situation awareness (level B) and even AV guidance (level A) could be provided. Other sections provide only level C support, which includes that VMS data is made available via digital interfaces. Furthermore, in this example the secondary road network is covered partially by map support (Level D), some rural areas have no support. This example illustrates how ISAD levels can be used for a simple description of what AVs can expect on specific parts of a road network.

[1] https://www.inframix.eu/

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

Figure 1: Levels of the Infrastructure Support for Automated Driving

2 The TransAID project

Below, the TransAID project is described. First, traffic management and policy as it is today is described to provide a starting point from which TransAID built. Next, we provide some background to automated driving (AD) and its relation to infrastructure. Since TransAID focusses on managing Transition of Control (ToC) in Transition Areas (TAs) those concepts are explained in section 2.3. The next two sections describe the approach of TransAID to study TAs and the solutions resulting from that approach. Finally, the last section provides the first steps towards a governing framework on how to detect and manage TAs in practice.

2.1 Traffic management and transport policy 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. Traffic control optimisation will depend on the goals a city would like to achieve – throughput, safety, environmental impact or comfort - and the weight applied to them 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 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 and smartphone apps (also for charging stations in case of electromobility) means 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 road authority as traffic and travel information service provider diminishes.

Another new trend in traffic management is to not just look at single locations, but rather to use the entire network to distribute traffic more wisely and as such postpone or even prevent the formation of congestion. Tactically streamlining, by coordinating road works, performing incident management, proposing alternative routes, etc. is then done via regional agreements and collaborating teams of operators and policy makers that exchange the necessary information. A promising way of turning traffic management into a very lean service is by means of Key Performance Indicators (KPIs), making the entire system performance-based.

Finally, the paradigm of Traffic Management as a Service (TMaaS) and/or a collaborative approach by public and private service providers cause shifts in the roles and responsibilities when it comes to traffic management. However, policymaking is clearly still the responsibility of the road authority. A potential shift in roles and responsibilities is also recognised with the introduction of AVs. Such vehicles make decisions based on automation and possibly information from infrastructure and/or backend services. Hence, it becomes the question who is responsible for the consequences of such decisions.

2.2 Vehicle and infrastructure automation

The deployment of (Cooperative) Automated Vehicles ((C)AVs) is not a goal in itself, however, to realise the potential benefits, CAVs need to become an integral part of the urban mobility system. How can public authorities prepare for AD? What can they do to facilitate, anticipate and/or regulate it? Various initiatives have been trying to identify and structure possible actions that cities can take to progressively introduce AD (see section 3).

CAVs connected with an intelligent environment can potentially contribute significantly 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 continuing growth and investment in fully or highly automating current driving tasks and the introduction of AVs, with the role of the human driver changing and/or diminishing. At the same time, the deployment of Cooperative Intelligent Transport Systems (C-ITS) using, e.g., V2X technology will not only be a key enabler for distributed coordination of CAVs but, combined with intelligent traffic management and control applications, will also enable the road infrastructure to monitor, support and (in theory) orchestrate vehicle movements.

V2X technology will allow to target vehicles individually, with them effectively becoming both sensors and actuators in the control system. In a broader setting, more and more countries are finding ways to enable C-ITS on their major roads, albeit mostly in pilot trials which will, in turn, facilitate the uptake of the so-called Day 1 and Day 1.5 services. Since TransAID's scope lies somewhat further in the future, those services are assumed to have gained some maturity and market penetration.

To describe the capabilities of AVs, automation levels are commonly defined by SAE International in J3016 (SAE International, 2018). This standard defines 6 levels of automation, starting from manual driving (level 0) up to full automation in all roadways and environmental conditions (level 5). In present times, first level 3 systems like driving in automated mode on motorways under constant supervision, are reaching the markets, where the vehicle itself monitors the environment and fulfils most aspects of the dynamic driving task. In case the system is not able to handle a situation, the human driver must respond appropriately to a request to intervene.

In more recent years, the concept of the Operational Design Domain (ODD, see section 1.4.1) has gained traction and provides a more refined concept to describe the capabilities of (C)AVs. However, this concept is still under development and there are many discussions on how to describe the ODD and what components it should include. In addition, it is recognised that the ODD has a dynamic nature. That is, the parameters which define whether a vehicle can operate in automated mode constantly change due to, for example, environmental factors (i.e., weather, light), available (digital) infrastructure, other road users and possibly the state of the driver.

Similar to the SAE levels and the ODD concept, INFRAMIX has proposed a classification scheme, called ISAD levels, in order to classify and harmonise the capabilities of a road infrastructure to support and guide AVs (see section 1.4.2). These levels can be assigned to parts of the network in order to give AVs and their operators guidance on the "readiness" of the road network for the coming highway automation era.

As mentioned, there are many factors that influence the ODD. The dynamic nature of the ODD provides an opportunity for the involvement of traffic management. Road authorities / operators could gain a new role to support AVs as changes to infrastructure, traffic systems and traffic centres may be needed to (further) facilitate AD. For example:

- Evaluate where and where no AD is allowed (i.e., no-AD zones);
- High traffic intensity may be outside the ODD, which requires dynamic ODD management;

- Road works have to be handled differently, additional measures are required (e.g., safe havens for minimum risk manoeuvres (MRM)).

And, the example which is the focus of TransAID: TAs. Situations where (C)AVs reach the limit of their ODD and collectively have to transition control to the driver in a limited area. This example and related aspects are elaborated on in the next section.

2.3 Transition of Control and Transition Areas

Some situations require the intervention of the human driver or the automation system, for example in case the system interpreted a situation in a wrong way, or an obstacle is suddenly appearing on the road. Therefore, it is necessary that control of the vehicle can be 'transitioned' from vehicle to driver and vice versa. Furthermore, some AVs could be supported by a remote control centre. In that case, not the driver, but a (remote) operator intervenes. Such interventions, include a shift of responsibility, when for example the system is unsure about an upcoming situation and needs the driver/(remote) operator to take over control and thus full responsibility. In TransAID, we refer to this as Transition of Control (ToC). Note that ToC can go both ways, from driver/(remote) operator to vehicle and vice versa.

One of the most critical factors of a ToC is the available timing. ToCs can happen instantaneous (e.g., by pressing a button) or need a specific amount of time. This is especially true when the system reaches an area where AD functions are no longer available. In these situations, the system must hand over control to the human driver/(remote) operator in the vehicle. In lower levels of automation this can simply be done by dropping control (so long as the driver follows his/her role of monitoring the system at all times), but when reaching higher levels of automation (or in case of abuse), this is more difficult, as the driver may be distracted from the driving task or even asleep. In these cases, the driver has to recognise that he/she has to take over and has to understand what reaction is appropriate to the current situation. This can be very time consuming and therefore needs an early detection of the necessity of a transition.

If the required time is not available, or the driver/(remote) operator is not responding, a level 3 and above system needs to perform a so-called Minimum Risk Manoeuvre (MRM). This manoeuvre is used to bring the vehicle into a safe state. This can be done simply by braking or in a more sophisticated way by, for example, a lane change to the emergency lane on motorways (also shown in the European FP7 project HAVEit (HAVEit, 2008)).

TransAID is focussing on ToCs from vehicle automation levels 2, 3 and 4 (where the system is in control) to levels 0 or 1 (where the driver/(remote) operator is in control), i.e., downward, and vice versa (upward). Furthermore, the project is especially looking at areas where multiple transitions are likely to occur very often: TAs. These are areas on the road in front of or after e.g., construction sites or complex intersections, which cannot be handled by AVs. TransAID does not consider singular transitions happening anywhere else, e.g., due to a sensor malfunction. In addition, situations where AVs (explicitly) might crash are not in focus. However, the solutions designed by TransAID could be applied to those situations as well.

Why, when, and where exactly ToC is triggered and how, where, and when it impacts the traffic KPIs depends on, in general, three factors: the environment, the AD functions and the ToC process.

The environment is defined as everything that surrounds the AVs and is thus outside the system boundary. Each change in the environment can change the vehicle behaviour and vice versa. The environment contains static, semi-static and dynamic elements. The **static** elements consist of the infrastructure layout (i.e., number of lanes, intersections, merging areas, bus lanes, crosswalks, road markings, road furniture, etc.) and the elements not being part of the road infrastructure and sometimes representing obstacles limiting the sensing capabilities of AVs (i.e., buildings, trees, foliage, etc.). The **dynamic** elements consist of surrounding vehicle types, vulnerable road users (e.g., pedestrians, bicyclists), weather conditions like rain, snow, or mist and dynamic traffic management elements like traffic lights, VMS images, and connected and/or cooperative messages from infrastructure, service providers, and other vehicles. Finally, the **semi-static** elements consist of temporary elements, for example, used for road works (e.g., pylons, truck mounted attenuators, yellow markings, barriers, additional traffic signs, etc.) or damaged infrastructure (e.g., pothole, bad road surface) that is usually repaired within days.

How a vehicle reacts to the environment depends on the exact implementation of the AD functions and thus the ODD. For example, a level 4 vehicle might be able to cope with a road works scenario, while a level 3 vehicle might not. Besides the high-level SAE classification, the details of the AD functions (or ODD) also impact the triggering conditions for a ToC and its effects. This impact is two-fold. On the one hand, the details determine the exact conditions prior to a ToC and thus the triggering conditions (i.e., cause), and on the other they determine the traffic situation after a ToC (i.e., effect).

The ToC process implies interactions between the system and the driver/(remote) operator during an upward or downward ToC. This process is important, because during the interactions, it is expected that the driving behaviour of the car will change and thus have an impact on its environment (e.g., other cars and traffic monitoring sensors). Because of this change, traffic flow and/or traffic safety might improve or deteriorate. How exactly the behaviour of the vehicle changes depends on several aspects. Firstly, the **Human Machine Interface (HMI)** design is important for a ToC, as certain elements can have large impact on the process. An example is the way the vehicle signals the driver/(remote) operator that attention is needed, which may vary from vehicle to vehicle and can impact the duration of the ToC process (Petermeijer, Cieler & de Winter, 2017). Also, the fluidity of the ToC depends on whether the ToC is implemented at once or stepwise. Secondly, the **Human Factor**. Many studies have been done on how people respond to ToC, specifically in relation to the HMI. The most challenging situation is probably a level 3 driving automation vehicle (Gold et al., 2017). At that level, most of the driving functions are performed by the vehicle and the vehicle monitors the driving environment, but the driver is expected to respond at any moment, if required. Since, by definition, the driver is not required to monitor the driving environment at level 3, situation awareness is very low. It will require some time before the driver is ready to take over control, but that is only possible if time allows. Therefore, how exactly the vehicle behaves during a ToC from level 3 downwards, depends largely on the prediction capabilities of the vehicle and on the capabilities / skills and level of arousal (alertness, attention level and information processing) of the driver. The last aspect is the exact **implementation of the driving when the automation level changes**. Not much can be found on how different vehicles implement level change functions. This will be dependent on specific implementations of different Original Equipment Manufacturers (OEMs), which leaves many questions open. For example, does the vehicle allow any change to the driving style of the AV (e.g., sporty, comfort, eco, etc.), including changes which affect the required driver attention. Exactly what attention is required from the driver at certain levels of driving automation? Depending on the answers to such questions, the exact vehicle behaviour during ToC can differ. For example, in our simulations we assumed (C)AVs extend the gap to the vehicle in front of them in preparation of a ToC to allow for safer (more relaxed) conditions when the driver/(remote) operator has to take over.

2.4 The TransAID approach

Within the TransAID project, a system was developed to manage traffic in TAs. The system follows a hierarchical approach, where vehicles with different automation and communication capabilities share information with the infrastructure (see Figure 2). TransAID therefore takes into account a foreseen mix of conventional / legacy vehicles (LV), connected non-automated vehicles (CV), AVs and CAVs. The infrastructure will integrate the acquired information at the Traffic Management System (TMS). The TMS will generate progression plans for the vehicles which are taken over by the infrastructure and communicated to the vehicles, either by I2V communication or (in case of non-equipped vehicles (LV/AV)) by e.g., VMS. The purpose of the system is therefore first to minimise the number of occurrences of ToCs in the TAs. In case corresponding measures are not resolving all issues and ToCs still take place, the system helps the vehicle currently performing a ToC by, for example, guiding it to a safe spot.

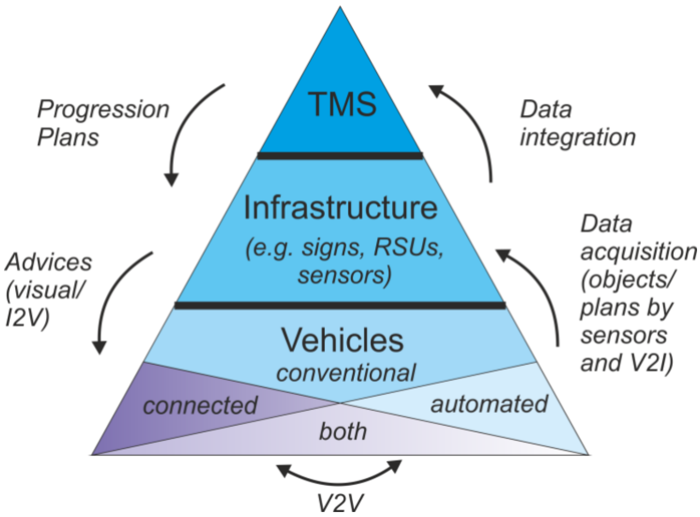


Figure 2: Hierarchical traffic management in TransAID

In TransAID, these kinds of measures are focussing on CAVs only. In addition, the system tries to reduce negative impacts (like reduced efficiency or safety) of the occurring ToCs to other road users, by, for example, informing other vehicles about the problems of the ToC performing vehicles or by separating AVs from non-automated ones. Informing other vehicles without communication was implicitly included in the simulations via the vehicle mixes and the way those vehicles respond to measures. In addition, outside the simulations signalling to vehicles without communication was studied and reported on in TransAID deliverable D5.4.

It is important to mention that in terms of connected (automated) vehicles TransAID is only focussing on ITS-G5 communication. Other kinds of communication (5G, etc.) may also be used, and the TransAID techniques may also be applied to those, but those are out of the project's scope.

To test and study the approach described above, TransAID started out with identifying several use cases with different kinds of TAs and defining the relevant aspects. Next, the simulations for those use cases were created and as a basis for the simulations several vehicle models were implemented to create the correct behaviour for lane changing (including cooperative versions), car following (including (Cooperative) Adaptive Cruise Control ((C)ACC)) and ToC/MRM algorithms. These models were created using a solid theoretical background, however, the availability of real-world data for input and calibration was very limited. The created models / simulations were used to create a baseline in order to evaluate the impact of the traffic measures.

The traffic measures were developed and implemented to mitigate the effects of ToC events in TAs. Specifically, for each of the selected use cases the effects of the TransAID measures are evaluated with respect to the baseline regarding emissions, safety, and efficiency. At this stage, ideal communications were used which means that realistic communication aspects like lost messages, channel overload, signal range, etc. were excluded. As a result, the principal of the measures could be studied without being limited by possible technical communication barriers.

While implementing and testing the traffic measures TransAID also identified or created the needed message sets and protocols to implement the measures using V2X communications. To that end, no new message sets were needed, but (minor) extensions to CAM, DENM, MCM and MAPEM were necessary. Especially MCM from the Manoeuvre Coordination Service (MCS) is key to multiple types of use cases. Therefore, it is necessary to define an MCS that is valid for all types of scenarios. Aligned with the work of ETSI and by actively contributing, TransAID has proposed an MCS where the infrastructure takes an active role to facilitate the manoeuvres of vehicles and to increase the overall traffic flow and safety.

The traffic management measures designed in TransAID also require that CAVs and road infrastructure units have an accurate perception of the environment. In addition to the MCS, TransAID has contributed to the evaluation and evolution of ETSI's Collective Perception Service (CPS) for cooperative perception.

Combining the work on the traffic measures and communications, the iTETRIS framework (Rondinone et al., 2013) was used to evaluate the selected use cases while deploying the traffic measures using realistic communications (with respect to those with ideal communications). The goal was to see if the communications impacted the effectiveness of the measures in any way.

Finally, the feasibility of measures and communications introduced were implemented in real-world demonstrators. The real-world implementation was done by performing three different feasibility assessments. Two of them have been performed on test tracks in Germany, and one on public roads in The Netherlands. On the test tracks, several detailed tests of all scenarios have been performed. It must be mentioned, though, that the implementation was done in a prototypic way.

2.5 TransAID services and use case results

Below we discuss the results of the approach described in the previous section. For the most part this is a summary of the meta-analysis presented in TransAID deliverable D8.2 which discusses the results in much more detail.

2.5.1 Use case selection

As pointed out in section 2.3, causes for ToC or MRM can be found in several factors (i.e., environment, AD functions, ToC processes) and can be based on anything that causes the AV to reach the limit of its ODD. Moreover, any combination of factors might trigger a ToC as well. Since any combination can result in different pre- and post-conditions suitable for investigation, in theory any combination should be considered as a separate use case. In combination with the many variable aspects to consider for each of the factors (e.g., OEM-specific implementation of AD and ToC functions, human behaviour in unprecedented situations, etc.), such an approach would result in too many use cases to study.

A rating process was adopted to identify the most suitable and interesting use cases. After that, consolidation work was initiated to eliminate observed overlap between some of the proposed use cases. In fact, it was identified that situations described in certain use cases could be solved by the measures described in other use cases. It was observed that the resulting use cases could be grouped in use cases categories associated with common measures. Five "services" defined as use case categories were identified:

1. Prevent ToC/MRM by providing vehicle path information
   To prevent ToCs/MRMs, detailed information is provided about the path a CAV should take.
2. Prevent ToC/MRM by providing speed, headway and/or lane advice
   This service provides speed, headway and/or lane advice to vehicles to prevent the

initiation of ToC/MRM due to complex traffic situations emerging from either planned or unpredictable events.

3. Prevent ToC/MRM by traffic separation
Different vehicle types (CAV, AV, CV, LV) are separated by giving lane advice per type before critical situations. Vehicle interactions are reduced to reduce the chance of ToCs/MRMs and thus prevent those.
4. Manage MRM by guidance to safe spot
In case a vehicle is going to perform an MRM, infrastructure helps by providing detailed information about possible safe stops.
5. Distribute ToC/MRM by scheduling ToCs
Whenever multiple ToCs need to be executed in the same area, this service distributes them in time and space to avoid collective ToCs and possibly MRMs in a small area.

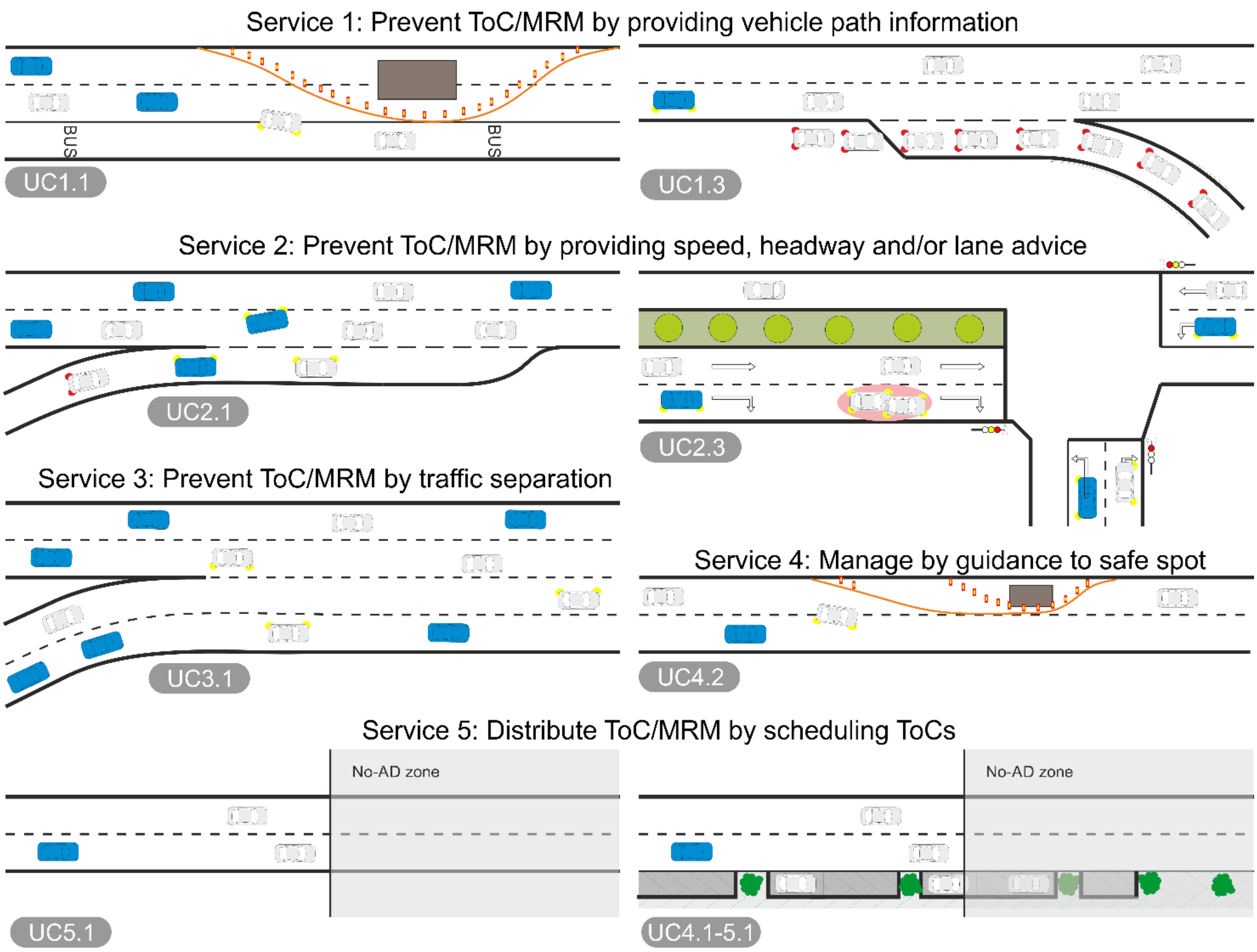


Figure 3: TransAID service and investigated use case overview (further details in Appendix A)

A selection of use cases / scenarios to be examined during the first project iteration was conducted based on experts' intuition and rating. The rating was made considering the limitations of each use case, its impacts on real-life traffic operations, and the requirements for the representation of use cases in a simulation environment from AV modelling, traffic management (TM) and communications perspective. Based on the results of this rating, scenarios from use cases 1.1, 2.1, 3.1, 4.2 and 5.1 (see Figure 3 and TransAID deliverable D2.1 for the full list) were selected for examination during the first project iteration. That iteration provided many insights, which were used to select new use cases / scenarios for the second iteration (i.e., 1.3, 2.3, 4.1+5.1) and two from the first iteration to be studied further. These partly focus on new situations and others combine multiple measures (services) into one scenario. In addition, during the second iteration, the vehicle models were refined (e.g., ToC/MRM behaviour, ACC) and additional concepts were added such as CACC and cooperative manoeuvring (see TransAID deliverable D3.1 and D3.2). An overview with a brief description of each selected use case can be found in Appendix A and a more detailed description of the simulation / scenario setup in TransAID deliverable D2.2.

2.5.2 Simulation setup and baseline

From the baseline simulation runs we found that ToCs do not significantly disrupt traffic flow performance unless CAVs establish increased car-following headways during the ToC preparation phase. Disruptions escalate in case of CACC driving, increased share of CAVs in the fleet mix, and the occurrence of multiple ToCs within a narrow temporal window and spatial domain. Furthermore, in the case that a ToC is unsuccessful or not possible, unmanaged MRMs (taking place in lane and not being guided towards safe spots) can induce significant traffic disruption as well. On the other hand, simulation results indicated that cooperative lane changes minimise the frequency of ToC/MRM and their consequent adverse impacts on traffic flow operations. The benefits of cooperative lane changing are amplified with increasing share of CAVs and especially upstream of lane drop locations.

2.5.3 Traffic measure evaluation

Comparing the baseline with respect to the simulations with traffic measures and ideal communications, we could evaluate the measures with respect to the efficiency, safety and emissions KPIs. A trade-off was observed between traffic safety versus traffic efficiency (as measured via throughput and travel times). It is often inherently difficult or even impossible to optimise both in the same context. Hence, typically a policy choice needs to be made, as to which of the two will have to be prioritised. Otherwise, results either improved or remained similar for all use cases and KPIs, except for use case 3.1 (see Table 1 on the next page and TransAID deliverable D4.2).

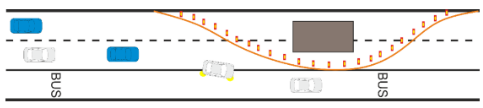
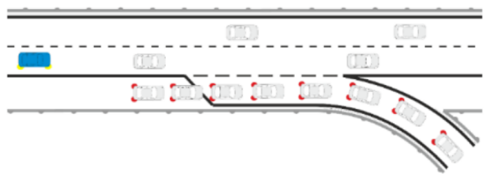
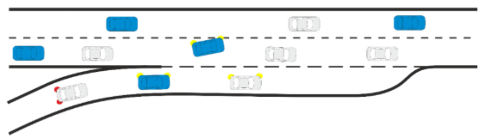
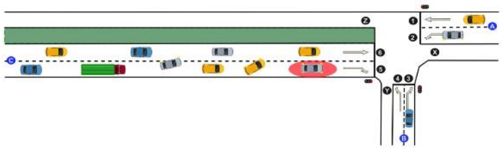
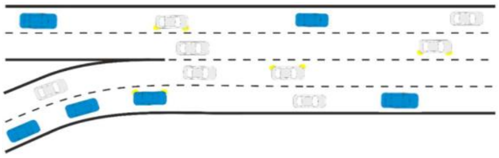
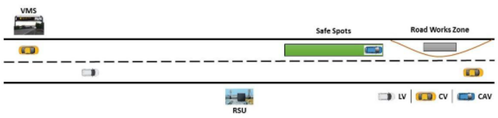
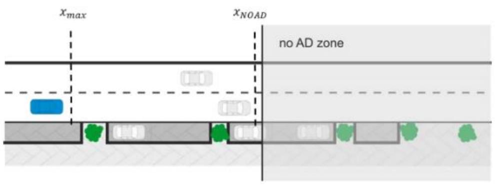
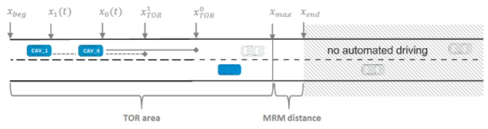
All use cases have in common that a reduction of MRMs is possible by providing infrastructure advice. Such advice, and the availability of safe spots (i.e., areas where a vehicle can safely stop), clearly reduces the number of stopped vehicles blocking the road.

There is also a heavy dependence of the results on the mixture of vehicle types, in addition to the observation that less efficient traffic management performance is obtained for a higher Level Of Service (LOS; HCM 2010). The latter is in part logical, as for higher LOS there is more prominent congestion and the physical limits of the infrastructure remain a hard obstacle. By itself this is not a problem for TransAID, as the focus of the traffic management schemes is to prevent/postpone traffic breakdowns before they occur.

2.5.4 V2X Communications

As the next, step realistic V2X communications (see TransAID deliverable D5.1, D5.2 and D5.3) were added to the simulations (see TransAID deliverable D6.1). To this aim, TransAID created (minor) extensions to CAM, DENM, and MAPEM, and proposed a message format for the MCM, which was not defined by ETSI yet, but is now being developed. The simulations showed that especially the MCM from the MCS was key to multiple types of use cases.

Table 1: Results of the simulations on the three KPIs[2]

Use case	Efficiency	Safety	Emissions	Comments	Schematic overview of the use case
1.1	~	+	~	Safety critical events reduced by 45% to 70%, depending on LOS and traffic mix.	
1.3	+	+	+	For higher traffic intensities and a larger share of AVs, the effects diminish but are still positive. When the queue grows too large and vehicles stop on the main road, safety and efficiency are affected strongly.	
2.1 (1st)	~	+	~	Large safety improvement and marginal improvements for both efficiency and emissions.	
2.1 (2nd)	-	+	-	This use-case identified a clear trade-off between safety and throughput, depending on merging settings.	
2.3	+	+	+	As long as traffic remains stable all effects are positive, performance becomes worse on all KPIs when breakdown occurs, but still less severe compared to the baseline.	
3.1	~	-	~	Safety is severely affected due to increased number of cut-in lane-changes. Increased CAV share and cooperative manoeuvring seems promising to improve the results.	
4.2 (1st)	~ (U) ~ (M)	+ (U) + (M)	+ (U) + (M)	Large safety improvements. Safety effects are smaller for a higher % of AVs / LOS.	
4.2 (2nd)	~ (U) + (M)	+ (U) + (M)	+ (U) + (M)	Increased share of AVs and higher LOS dimish the safety effects, as expected.	
4.1 + 5.1	+	+	+	Large improvements on all measures. Higher traffic intensities result in relatively larger improvements.	
5.1	+	+	+	Large improvements on all aspects due to the smoothening of disturbances.	

[2] ~ no change, + improvement, - decrease, U - Urban, M - Motorway, 1st / 2nd - project iteration.

Also, the traffic management measures designed in TransAID require that CAVs and road infrastructure units have an accurate perception of the environment. In addition to the MCS, TransAID has contributed to the evaluation and evolution of ETSI's Collective Perception Service (CPS) for cooperative perception. We have demonstrated that cooperative perception can improve CAVs perception capabilities when the trade-off between the perception capabilities and communications performance is balanced. Furthermore, the reliability of V2X communications has been addressed in TransAID using different and complementary techniques: compression, congestion control and acknowledgements (see TransAID deliverable D5.3). These techniques are also key to improve the V2X communications performance to support advanced applications and services.

V2X communications support and allow the deployment of the TransAID use cases. TransAID has conducted one of the major simulation studies considering a large number of use cases, and vehicles and road side units (RSUs) equipped with multiple V2X services. Our simulations with realistic communications confirmed that an adequate configuration of the V2X communication protocols and settings allow a robust operation of the considered use cases. The simulation results for the project's first and second iteration use cases showed very similar results to the previous evaluation with ideal communications (see TransAID deliverable D6.2). All traffic measures were found robust enough to show the same results with or without realistic communications, even considering increased traffic demand and thus more communication enabled vehicles.

2.5.5 Communication with non-equipped vehicles

Besides the V2X communication, the communication to unequipped vehicles was of importance and was studied outside the simulations (see TransAID deliverable D5.4). We considered two parts: on the one hand, infrastructure needs to inform unequipped vehicles about issues on the road. On the other, AVs themselves should provide information about their actual state to their surroundings, to avoid negative impacts.

With regards to the infrastructure information, it needs to be mentioned that visual information on signs, variable or static, will never be as precise as V2X communication could be, especially when looking to individual advices. Nevertheless, infrastructure can provide valuable information also to unequipped vehicles by signage, e.g., in terms of speed limits, distance (gap) advice or dynamic lane assignments. It will be required to create additional road signs dealing with AVs, at least showing that, e.g., an area is prohibited for AVs or an area where only AVs are allowed.

Regarding signals from AVs, TransAID's solution of having LED light strips at the back of AVs will be beneficial in any case, but the exact content of such lights needs to be defined by performing more detailed analyses of such components. This goes to all external and dynamic HMI components of AVs. In this light, it will be crucial to have an intuitive way of understanding the automation related additional information. One key question in this area is if driving with enabled automation should be indicated by an additional external light, and if so, where should this light be and what colour?

2.5.6 Real world feasibility testing

As a final step in our use case assessment, the feasibility of measures and communications introduced were implemented in real-world demonstrators. The real-world implementation was done by performing three different feasibility assessments. Two of them have been performed on test tracks in Germany, and one on public roads in The Netherlands.

On the test tracks, several detailed tests of all scenarios have been performed, revealing that all traffic management measures could be successfully integrated and applied to AVs in all use cases and scenarios. This includes the successful setup of the RSI and the AVs. It must be mentioned, though, that the implementation was done in a prototypic way.

The development of related series products would require much more testing under real world conditions, which will be challenging at the current time since no highly automated vehicles are present on the roads. Nevertheless, it is very important to start the investigations at present times. As standardisation of messages is happening already now, and it is very important to include the role of the infrastructure at this stage. All details of the real-world implementations can be found in TransAID deliverable D7.2.

2.6 Towards a governing framework for Transition Areas

In addition to the design and technical implementation of traffic measures in simulation and the real world, TransAID gained some insights on issues of a less technical nature. For example, it was determined a close collaboration between OEMs and (N)RAs would be beneficial in the identification and managing of TAs. To facilitate such a collaboration TransAID proposes a traffic management framework in the form of an intermediary service provider, acting as a trusted (and possibly mandated) third party (see Figure 4 and TransAID deliverables D4.1 and D4.3).

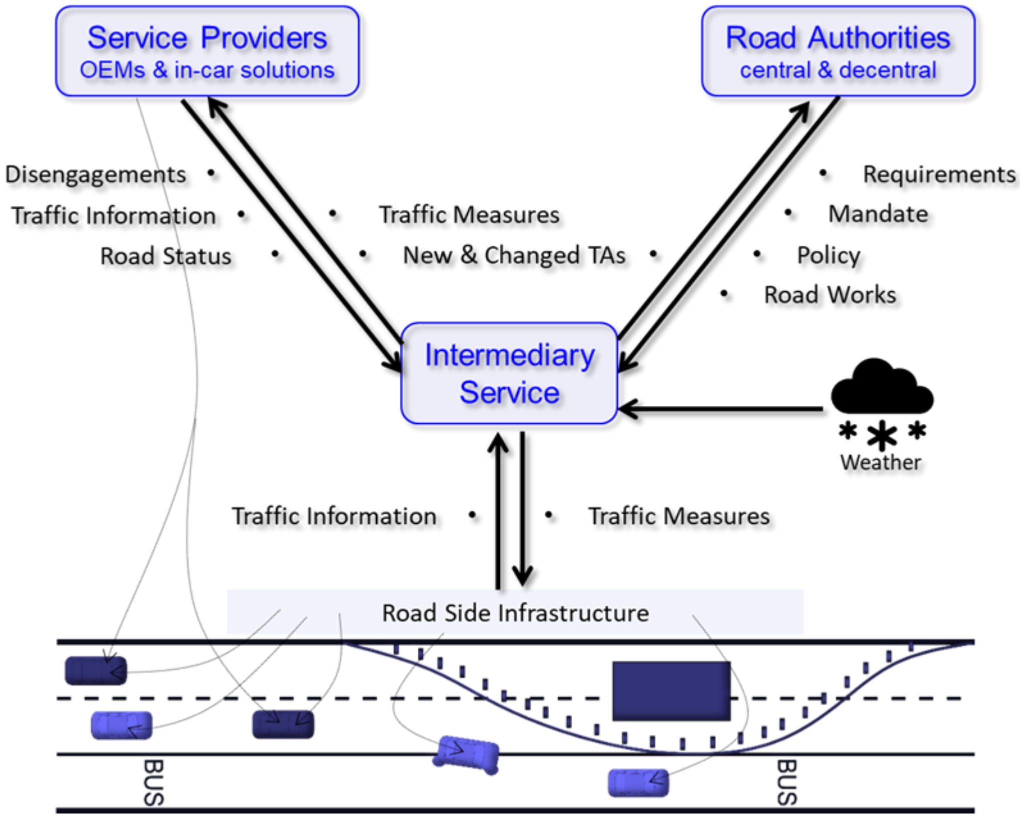


Figure 4: Schematic overview of TransAID's intermediary service approach.

The framework allows TransAID to be scaled up and generalised. We approached this from both a technical and a business-oriented perspective. For TransAID to become part of a complete traffic management system, we focused on the technical side on how to detect TAs, select (and possibly combine) services, and then detect when they are most appropriately timed for deployment. To this end, detection can be done via the infrastructure (e.g., road sensors or even digital communication infrastructure), via the OEMs, or by comparing an infrastructure's newly defined ISAD levels to the ODD of the vehicle.

Considering the mentioned technical challenges (detecting TAs, selecting services, and timing their deployment), the intermediary service bridges all these parties in such a way that the detection of TAs is performed in a centralised way, and OEMs and (national) road authorities have a single point of contact for providing and receiving information about TAs.

3 Facilitating and anticipating automated driving

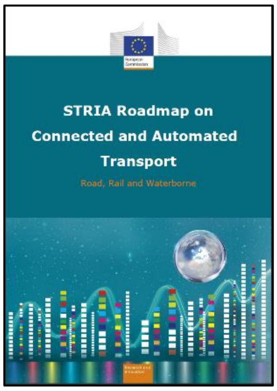
There already exist many roadmaps, guidelines and action plans that aim at bringing AD to public roads. They have different origins like national and international projects, platforms, industry and governmental institutes. The intent of these documents is very similar as is their typical structure. Usually, they first give an overview of major trends in the domain of mobility: digitalisation, connectivity, and automation. Next, they provide background information to enable the reader to better understand the bigger picture, as well as the stakeholders involved. Thereafter, they estimate the impact of the trends to a specific context, for example traffic safety, traffic management, public transportation, mobility in urban areas, policymaking, etc. Often this leads to questions and concerns, which are translated into research questions, needs and/or required action. Finally, most roadmaps indicate a timeline to provide a planning horizon.

An inventory of roadmaps, guidelines and actions is available in the knowledge base of Connected Automated Driving Europe[3]. This inventory is the result of an analysis of the CARTRE-project that explored the variety, differences and commonalities of roadmaps and national action plans[4]. The inventory and analysis include documents that were published in 2018 and before. Since then, several new documents were published and those most relevant to the TransAID project are listed below.

STRIA Roadmap on Connected and Automated Transport: Road, Rail and Waterborne

European Commission's Directorate-General for Research and Innovation, 2019

Download link



The essence of this document are roadmaps for the road, rail and waterborne transport modes explaining what has to be done to overcome the hurdles and gaps between the state of the art in CAT in Europe and the European Union's objectives. These roadmaps are structured along technical and non-technical thematic areas. They identify effective initiatives that work hand in hand to advance innovation. Each of these initiatives is supported by a sequence of actions that mainly relate to necessary research and innovation activities but also to other measures to accelerate deployment. These actions are put on a timeline indicating whether they are needed in the short, medium or long term, meaning until 2023, until 2030, or beyond 2030.

This roadmap identified eight thematic areas of Connected Automated Driving (CAD); a division of themes for research and innovation in the field of connected and automated driving:

1. In-vehicle enablers
2. Vehicle validation
3. Large scale demonstration pilots to enable deployment
4. Shared, connected and automated mobility services for people and goods, including long haul transports (persons, goods, public)
5. Socio-economic impacts; User / public acceptance
6. Human factors

[3] https://knowledge-base.connectedautomateddriving.eu/roadmaps/list-strategies/

[4] CARTRE Deliverable 2.2 Overview and analysis of ART stakeholder groups and initiatives

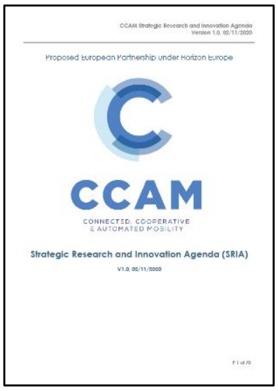
7. Physical and digital infrastructure and secure connectivity
8. Big data, Artificial Intelligence and their applications

For each thematic area R&I initiatives and actions have been described, resulting from an intensive stakeholder dialogue process involving Member States representatives and experts from industry and academia. Thereafter assessments have been made on Priority rankings of initiatives, Timing and types of actions per initiative, Responsibilities per initiative, and Links between initiatives. The full list of initiatives and actions is available in the roadmap. The three highest ranked initiatives are Vehicle Validation, Physical & Digital Infrastructure, and Traffic Management System.

CCAM Strategic Research and Innovation Agenda

CCAM Partnership, 2020

Download link



The CCAM Partnership Vision is to ensure European leadership in safe and sustainable road transport through automation.

With full integration of CCAM in the transport system, the CCAM partnership shall contribute to achieving the following positive impacts for society:

- Safety: Reducing the number of road fatalities and accidents caused by human error
- Environment: Reducing transport emissions and congestion by optimising capacity, smoothening traffic flow and avoiding unnecessary trips
- Inclusiveness: Ensuring inclusive mobility and goods access for all
- Competitiveness: Strengthen competitiveness of European industries by technological leadership, ensuring long-term growth and jobs.

The Strategic Research and Innovation Agenda (SRIA) for CCAM defined specific objectives, which contribute to generic objectives that will yield the expected impacts. The SRIA for CAM builds the foundation for delivering the specific objectives between 2021 and 2030. Furthermore, the partnership identified possible performance indicators to support the partnership progress monitoring and to assess the contribution of the partnership in achieving the objectives.

In addition, the SRIA for CCAM also provides details of what research and innovation (R&I) actions are required; why and when these R&I actions are needed; and how these actions contribute to achieving the objectives and initiating the transformative process in society.

Connected Automated Driving Roadmap

European Road Transport Research Advisory Council (ERTRAC), 2019

Download link

This roadmap for CAD contributes to the long-term vision of ERTRAC for the transport system. In one sentence: by 2050, vehicles should be electrified, automated and shared.

The main objective of the ERTRAC Roadmap is to provide a joint stakeholder view on the development of CAD in Europe. The Roadmap starts with common definitions of automation levels and systems, and then identifies the challenges for the implementation of higher levels of AD functions. Development paths are provided for three different categories of vehicles.

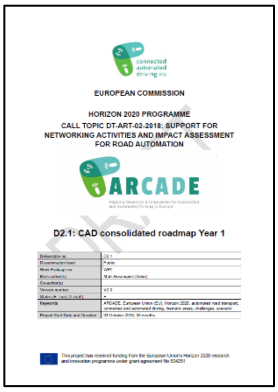
The Key Challenges identified within the three areas (Users & society, System & services, and Vehicles & technology) should lead to efforts of Research and Development: ERTRAC calls for pre-competitive collaboration among European industry and research providers. The key role of public authorities is also highlighted: for policy and regulatory needs, and support to deployment, with the objective of European harmonisation.

CAD must therefore take a key role in the European Transport policy, since it can support several of its objectives and societal challenges, such as road safety, congestion, decarbonisation, social inclusiveness, etc. The overall efficiency of the transport system can be much increased thanks to automation.

CAD consolidated roadmap Year 1

ARCADE project, 2019

Download link



This roadmap's main objective is to bring together a consolidated multi-stakeholder view on the development of CAD in Europe into three development paths, highlight ongoing activities and identify challenges and key priorities extracted from thematic areas.

The roadmap consolidates the work from its thematic areas, knowledge base, related projects and initiatives, as well as providing common basic definitions of automation levels and systems and identifies the challenges for the implementation of higher levels of AD functions.

The roadmap contains key challenges identified to guide required efforts of pre-competitive collaboration R&D among EU industry and research providers and highlights the key role of public authorities for policy, regulation and support to deployment.

Additionally, together with the ARCADE stakeholder network 7-8 key priorities for each thematic area have been identified (see figure 9 in the roadmap).

The roadmap also provides development paths for three different categories of AVs (Passenger cars, freight vehicles and urban mobility vehicles), fully in-line with the ERTRAC CAD roadmap, to show the indicated development paths to reach TRL 7 to 9. The focus for the development paths is towards high automation (L4) where research and innovation needs will be required.

This document concludes that the focus for the coming 10-year period in the development paths will be on highly automated vehicles (SAE L4) in mixed traffic and a selection of use-cases has been identified to illustrate this development as elaborated in the roadmap.

UK Connected and Automated Mobility Roadmap to 2030

Zenzic, 2019

Download link

In order to use the 2030 Vision to tangibly impact the roadmap and define its Milestones, a set of ten core deliverables to achieve by 2030 have been identified:

1. UK legal and regulatory framework is world-class and mature, promoting and enabling CAM to be deployed at scale
2. An enviable and robust safety record has been established in the UK and replicated around the world
3. A significant number of highly automated vehicles are delivering mobility in the UK
4. Society understands, accepts and is adopting CAM
5. Infrastructure is ready for increased deployment of CAM and has areas with highly connected roads
6. UK-based high-value jobs with rich skills pipeline in place
7. Capabilities and benefits are delivered by the UK throughout the CAM supply-chain
8. Greater certainty in emerging business models
9. Road networks are managed using new methods, delivering more efficient use of road space
10. UK is recognised as a leader in innovation in this developing ecosystem

The UK Connected and Automated Mobility Roadmap to 2030 utilised the interdependencies between Milestones to define threads of related Milestones: “Golden Threads”; rich insights that can be harnessed simply by selecting an orienting Milestone.

1. Legislation and regulation
2. Safety
3. CAM services
4. Public Acceptability
5. Infrastructure
6. Cyber Resilience

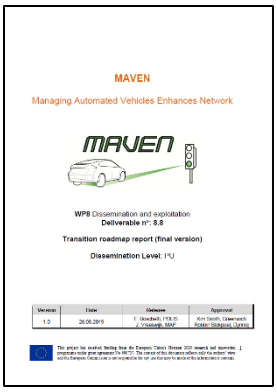
Contained in this roadmap is an exploration of the six Golden Threads, which relate to the ten core deliverables. These Golden Threads can be used to inform company strategies and decisions underpinned by a wealth of insights created by experts across industries.

Zooming in on a particular Milestone in the roadmap allows users to see the interdependent relationships around it, thereby understanding the associated enablers and deliverables that are linked to their point of interest.

Transition roadmap report

MAVEN project, 2019

Download link



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. 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 CAVs.

MAVEN has focused on the city readiness phases and in particular has explored V2X use cases and how AVs 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 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.

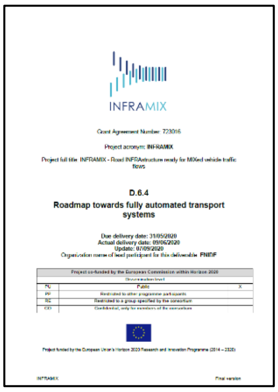
Three case studies were carried out by the MAVEN project in European cities, Greenwich in London, Helmond in the Netherlands and Braunschweig in Germany to illustrate different levels of city awareness and understanding of connected and automated vehicles and vehicle-to-infrastructure technologies and how they could transform mobility within cities. For each city MAVEN 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 regarding infrastructure requirements, transport policy and traffic management. A relevant statement in the conclusion section is that many of the issues discussed in the document do not have a final solution or conclusion. 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.

Roadmap towards fully automated transport systems

INFRAMIX project, 2020

Download link


INFRAMIX

Grant Agreement Number: 723016

Project acronym: INFRAMIX

Project full title: INFRAMIX - Road INFRAstructure ready for MIXed vehicle traffic flows

D.6.4

Roadmap towards fully automated transport systems

Due delivery date: 31/05/2020
Actual delivery date: 09/06/2020
Update: 07/09/2020
Organization name of lead participant for this deliverable: ENIDE

Project co-funded by the European Commission within Horizon 2020		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants	
RE	Restricted to a group specified by the consortium	
CO	Confidential, only for members of the consortium	

Project funded by the European Union's Horizon 2020 Research and Innovation Programme (2014 – 2020)

INFRAMIX Final version

This document outlines the roadmap of necessary activities and concrete actions to be undertaken by different stakeholders in order to meet some most urging challenges in the field of automated transport systems through INFRAMIX solutions, which encompass several innovative elemental technologies that concretely address the challenges of three traffic scenarios: dynamic lane assignment, roadwork zones, bottlenecks.

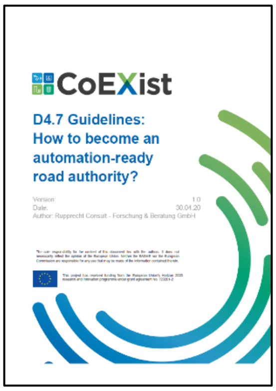
The roadmap describes INFRAMIX solutions and the developed elemental technologies, and how they are expected to advance the connected road infrastructure towards a fully automated transport system. Updating road infrastructure is referred to as a complex process involving several different stakeholders, each of them meeting a specific challenge towards the achievement of a specific goal. Despite these goals being complementary, they need detailed analysis and tailored solutions to guarantee their successful achievement. Likewise, all stakeholders need to coordinate their actions and jointly strive to a common objective. Otherwise, their efforts risk to be hindered or even blocked by other actors, in case of colliding interests. For this reason, the INFRAMIX roadmap addressed elaborately the implications for: industry, infrastructure operators and road authorities, local, national and European policy makers, research community, policy advisors and key influences, and general public.

The roadmap provides a 10-year timeline that is considered viable by the project consortium for an effective and timely implementation of the INFRAMIX solutions. This timeline includes integration with technology, standardisation, policy making, validation and deployment. In addition, awareness of solutions and coordination with other automated mobility stakeholders are highlighted as separate activities. The document concludes by stating that INFRAMIX outcomes have been well received by the international community of CAD stakeholders, but that they will be implemented incrementally, i.e., they will need constant and structured developments by all involved partners to ease the transition towards fully automated transport system through minimal interventions. Hence, further guidelines are needed to ensure the successful transfer of results to relevant stakeholders after the project's conclusion.

Guidelines: How to become an automation-ready road authority?

CoExist-project, 2020

Download link



This document describes the current state of automation-readiness in European cities, evidencing the need for guidance and knowledge exchange regarding CCAM. It presents the results of CoEXist's stakeholder consultation activities and reflects on the main aspects to be considered.

Furthermore, this document presents the developed automation-ready modelling tools and road infrastructure impact assessment methodology, respectively, setting a technical framework to investigate CCAM scenarios and evaluate expected effects on urban mobility.

In addition, the automation-ready tools developed within the CoEXist project have been used to evaluate the traffic impact of automation for eight strategically selected use cases in four different cities.

Also, the automation-ready planning framework is introduced, as well as its application in CoEXist cities for the development of concrete Action Plans, outlining key measures, the followed strategies and lessons learnt.

In this way, this report delivers concrete guidance, tools and methodologies to enable cooperative action and informed decision-making about the deployment of Cooperative Connected and Automated Mobility (CCAM), supporting road authorities in their way towards automation-readiness.

Recommendations about how local authorities can shape CAV deployment in alignment with their policy goals:

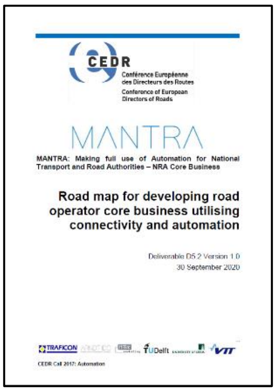
- Authorities should look at planning for Cooperative Connected and Automated Mobility (CCAM) as an element of a more fundamental change process: proactive action to get ready for the challenges of conducting planning processes towards CAV deployment.
- Planning for CCAM should be based on analyses of all modes and supported by all stakeholders (and not on an SAE perspective).
- Transport and infrastructure planning through adequate tools: automation-ready modelling functionalities & impact assessment framework, with strategically defined KPIs in relation to local policy goals.
- In addition to (old) risks, new opportunities for sustainable urban development arise, which can potentially spur flexibility and create room for experiments.

The key take-away of this document is that cities should be aware of the various opportunities, and challenges that arise from CCAM deployment. A structured & well-informed decision-making process, through holistic frameworks, is required to ensure sustainable and affordable services that align with local policy goals and respond to user needs.

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

MANTRA project, 2020

Download link


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

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

Deliverable D5.2 Version 1.0

30 September 2020

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

- What are the influences of automation on the core business in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes?
- How will the current core business on operations & services, planning & building and ICT change in the future?

The Road map for developing road operator core business utilising connectivity and automation consists of tables describing 92 actions, of which 22 priority actions, in different areas up to 2040. The actions are classified in three major categories:

- Actions with no regret – actions useful also for human-operated vehicles to be carried out due to present needs and other developments;
- Study and learn – actions to find out more about the technology, operation, benefits, costs and implementation issues in order to understand the potential, restrictions and feasibility of AD;
- Key actions for deployment – actions to safeguard NRA interests and with major future impact on NRA investments and operations.

A common key finding is that there are some inherent difficulties in supporting the ODDs as they depend on the capabilities of the sensors and software including AI of the AVs, and these capabilities are improving quite quickly with the evolution of related technologies.

Road map and action plan to facilitate automated driving on TEN road network

EU EIP project, 2020

Download link


EU EIP SA4.2

Task 3

Road map and action plan to facilitate automated driving on TEN road network – version 2020

This roadmap gathered information in several open workshops with road authorities and operators, with the L3pilot project, with external experts in the field of cost and benefits considering the ODD, and with European Commission representatives.

Stakeholders, road authorities and operators, have already been considering their position on automation, on different levels, in several initiatives. This is a continuous effort since the field of automation is constantly evolving. This roadmap document is part of this continuous effort and focuses on findings / efforts and a direction for future work within the following topics:

- Impact on and role of physical and digital infrastructure, with a specific focus on the concept of ODD.
- Cost and benefits of automation for road authorities and operators.

The document provides a list of 45 actions and recommendations many of which at least need to be addressed by road authorities / operators. For each action information is provided on other stakeholders involved, resources needed (money, time, power, cooperation, …) and timing (short term: next 3 years, medium term: next 10 years, long term: > 10 years).

The emphasis is clearly in learning more about the developments and evolution of higher level (SAE 3-4) AD including the related ODD requirements. Goal is to be prepared for AD, have influence on the development so that road network operation does not suffer but rather improves, avoid excessive investments in vain, and to reap the potential benefits as soon as possible. It is premature to commence deployments unless road authorities and operators are certain that the solutions invested in will not become obsolete in the short term. Some of the short-term actions, can be carried out with no regrets as they will benefit the road network operations already today and involving human-operated vehicles. Such relate to, for instance, provision of data in digital form, digitalisation of key processes, implementing cybersecurity, and provision of connectivity of the physical and digital infrastructure.

The actions and recommendations should be taken further by the road authorities and other stakeholders. Especially a structured dialogue between the road authorities / operators and the automated driving industry is considered important. It would be advisable to converge the large number of roadmap activities in Europe towards a smaller number of dedicated work streams.

To add to this library of roadmaps, guidelines, and action plans, the TransAID project considered it most meaningful to build upon the work of the MANTRA (Amelink, et al., 2020) and EU EIP (Kulmala, et al., 2020) projects. What sets their reports apart from the others is the concrete list of actions and recommendations that they include. Based on workshops with road authorities and road operators both projects produced an extensive list of actions and recommendations that affect the core business of road authorities and other stakeholders. These actions and recommendations were clustered by theme. Appendix B contains a complete list in which the actions of MANTRA and EU EIP are combined.

In a next step, the actions and recommendations that relate to the scope and results of the TransAID project were identified. Those actions are addressed separately in section 4. Instead of producing a roadmap and guideline document that is very similar to others, it was considered more valuable to summarise findings and results from the TransAID-project in light of actions and recommendations identified by others (in this case MANTRA and EU EIP). This approach is regarded helpful for relevant stakeholders to increase their level of understanding of an action or recommendation.

4 Contribution to actions for stakeholders and future steps

As written above in the conclusion of section 3, to prevent a similar roadmap to other initiatives with many duplications, TransAID decided to build upon the work of MANTRA (Amelink, et al., 2020) and EU EIP (Kulmala, et al., 2020). A complete list of actions and recommendations from those initiatives are grouped by topic and listed in Appendix B. From that list, those most relevant to the findings and results of TransAID are reflected upon below.

Considering four topics: physical infrastructure, digital infrastructure, traffic management, and intermediary role and stakeholder collaboration, a table is included for each relevant action. Each table encompasses information about the general TransAID contribution to the action, relevant TransAID use cases and results, roles of important stakeholders, timelines for the implementation of each action, recurring questions, and proposed future research and/or related / ongoing initiatives.

The considered stakeholders are OEMs, road authorities, road operators, service providers and standardisation bodies of which only the relevant ones are listed given the topic and/or TransAID insights. Regarding future research, other initiatives are mentioned if known at the time of writing. Otherwise, recommendations for future research are given. Furthermore, most of the stakeholder responses and/or recurring questions can be found in TransAID deliverable D8.2 in which the view of stakeholders is reported in detail.

Each of the tables below uses an EU EIP/MANTRA action as the title to link our contribution to the work of those initiatives. In some cases, we feel the title was somewhat incorrect or misleading, in which case we changed it slightly and included the original title directly below in italics. Furthermore, the content of some tables is related to more than one action, in which case additional related actions are listed below the title in italics. A special case is table TM3 (in section 4.3) which contains content not covered by one of the EU EIP/MANTRA actions and thus specifically added by TransAID. Finally, not each action (including the timelines) is covered by TransAID to the same degree, since TransAID contributed more to some topics than others.

A complete overview of the covered actions can be found as a list in the introduction of each subsection. In those lists, additional related actions are included as second level bullets.

4.1 Physical infrastructure

The penetration rate of connected and automated vehicles will increase, and physical road infrastructure will continue to play an essential role to facilitate this or even expedite it. Physical infrastructure includes road design (type of road, layout), road conditions (pavement, surface status), road furniture and facilities (markings, kerbs, traffic calming, traffic signs, h/w of traffic signals, h/w for V2X), in conformance with road safety regulations. The physical infrastructure information can be coded in digital maps.

The requirements for the physical infrastructure are related to the level of automation of vehicles for which the road is intended. For example, (C)AVs need consistent and understandable, well-maintained road markings in all situations and circumstances accurately represented in a highly up-to-date digital map and including information of the traffic signal phase. The INFRAMIX[5] project defined the ISAD levels (see section 1.4.2) to indicate what kind of support for (C)AVs can be expected from the infrastructure.

[5] https://www.inframix.eu/

A basic requirement for more advanced forms of AD might be some degree of digitalisation of the infrastructure (i.e., static road data coded in digital maps). In addition to facilitating the collection and distribution of dynamic traffic information (collective perception), the digital information is especially useful in case of lower penetration rates of cooperative (automated) vehicles, which limits the amount of information originating from other cooperative vehicles. To complement the information from collective perception in case of lower penetration rates, additional infrastructure sensors are needed to provide input for services like motorway merge, blind spot detection, trajectory planning, platoon organisation and cooperative manoeuvring.

Several examples of implications to the physical infrastructure because of increasing levels of automation are described in the tables below. These address the following topics:

- PI1: Additional emergency bays, wide shoulders and safe harbours
- PI2: Ramps and junctions
- PI3: Road categorization ISAD levels also for digital and physical infrastructure

PI1: Additional emergency bays, wide shoulders and safe harbours	
General TransAID contribution	TransAID neither targets (re-)design of physical infrastructure, nor provides a comprehensive analysis of requirements for deploying CAVs. The scope of the project is to identify requirements for road infrastructure (related to scenarios to prevent, manage / support or distribute ToC/MRM), and to identify potential barriers to facilitate CAV implementations. Additional emergency bays, wide shoulders and safe harbours / safe spots are part of those requirements.
Relevant use cases and results	In UC4.2 *Manage MRM by guidance to safe spot* and UC4.1+5.1 *Distributed safe spots along an urban corridor*, physical infrastructure, such as additional emergency bays, wide shoulders and safe harbours / safe spots may be required for real world implementation.
Important stakeholders and their role	**OEMs:** Develop CAVs that support stopping in a safe harbour / safe spot (possibly being advised by digital infrastructure in finding one). **Road Authorities:** Plan and design roads with safe harbours / safe spots around likely TAs. **Road Operators:** Support communications towards CAVs with location of safe harbours / safe spots. **Standardisation bodies:** Help with the definition of safe harbours / safe spots and the criteria.
Stakeholder responses	Physical infrastructure (including emergency bays and shoulders) is the basis of road transport and CAV deployment. Definition of "safe spot" or “safe harbour” is yet unclear. Constraints of road space should not be underestimated.
Timeline	*Below recommended steps are provided given different time horizons.*

2021-2025	Provision of safe harbours / safe spots in pilot projects and evaluation of necessity. Areas similar to bus stops, but long enough for freight vehicles with trailers, e.g., every 500m on pilot sites.
2026-2030	Safe harbours / safe spots similar to bus stops in case of narrow shoulders at intervals identified during pilots and ahead of tunnels.
2031-2040	Safe harbours / safe spots similar to bus stops in case of narrow shoulders at intervals identified during pilots and ahead of tunnels.
Recurring questions	Which guidelines do exist, if any, for improving road infrastructure (with respect to additional emergency bays, wide shoulders, and safe harbours) for deploying CAVs? How to define a "safe spot" or a “safe harbour”? What are the parameters of a “safe spot” or “safe harbour”, e.g., length and width to fluently stop in there? How many safe spots are required (e.g., per km, lane, TA)? What are the estimated costs for establishing an ideal physical infrastructure (e.g., additional emergency bays, wide shoulders, and safe harbours) for deploying CAVs at Level-3 and Level-4 respectively? How can be differentiated between safe spots and parking places (in urban contexts) or safe spots and emergency zones (on highways), if required?
Ongoing, relevant and/or future research and innovation activities	Development of requirements and guidelines for physical infrastructure improvement. Exploration of most cost-effective solutions. Implementation of pilots.

PI2: Ramps and junctions	
General TransAID contribution	TransAID neither targets (re-)design of physical infrastructure, nor provides a comprehensive analysis of requirements for deploying CAV. The scope of the project is to identify requirements for road infrastructure (related to scenarios to prevent, manage / support or distribute ToC/MRM), and to identify potential barriers for facilitating CAV implementation. The design of ramps and junctions needs to consider specific requirements of CAVs (including platooning).
Relevant use cases and results	Relevant use cases are: UC1.3 *Provide path to end of queue on motorway exit*, UC2.1 *Prevent ToC/MRM at motorway merge segments*, UC2.3 *Intersection handling due to incident*, UC3.1 *Prevent ToC/MRM by traffic separation*. Infrastructure redesign, such as ramps and intersections, might be required for CAV deployment. TransAID showed that the more conservative behaviour of CAVs requires more space or support for merging

	manoeuvres. In addition, CAVs might not be able to cope with unexpected circumstances around merge areas (exits, on-ramps, junctions) such as spillback from the exit onto the emergency lane.
Important stakeholders and their role	**OEMs:** Develop CAVs that can comprehend and enact upon personalised advice and information provided by the TMC side to support merging behaviour and/or traffic separation policies. **Road Authorities:** Plan physical and digital infrastructure around ramps and junctions to support CAVs with merging behaviour. **Road Operators:** Establish, support, and maintain physical and digital infrastructure necessary for the provision of real-time advice to mixed traffic about road status and traffic regulations. **Service Providers:** Develop services that provide real-time advice to CAVs with respect to road status and traffic regulations. **Standardisation Bodies:** Develop communication standards to empower I2V advice for cooperative manoeuvring and/or traffic separation policies.
Stakeholder responses	Physical infrastructure (including ramps and intersections) is the basis of road transport and CAV deployment. Constraints of road space should not be underestimated.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Identification of potential risks for (C)AVs on ramps and at junctions. Initiation of research and pilots to determine a merging strategy, e.g. how to enable (C)AVs enter ramps, and how to design ramp control and cooperative merging.
2026-2030	Determination of ToC for "ramps and junctions". Provision of design requirements for the length, curvature, markings of the ramps, to ensure adequate visibility and weaving sections for (C)AVs. Provision regulations for (equipped and non-equipped) vehicles in a merging situation, based on safety criteria.
2031-2040	Development of cooperative merging support systems. Implantation of research, and real-world testing starting with a simple traffic situation.
Recurring questions	How can digital infrastructure assist CAVs in merging sections? Which guidelines exist, if any, for improving road infrastructure (with respect to ramps and intersections) for deploying CAVs? How can planners have access to relevant ODD restrictions of CAVs to optimally plan infrastructure, especially ramps and intersections? In case further investment is needed, what are the estimated costs for establishing an ideal physical infrastructure (e.g., ramps and intersections) for deploying CAVs at Level-3 and Level-4 respectively?

Ongoing, relevant and/or future research and innovation activities	Ongoing research primarily focuses on the examination of cooperative manoeuvring on a UC basis. Emphasis has been already placed on cooperative lane changing, cooperative merging, platooning, autonomous intersection control and other scenarios. Moreover, distributed approaches have been favoured so far. Future research should address manoeuvre coordination considering a generic hybrid approach that utilises advantages from both distributed and centralised approaches. Relevant communication protocols should be also developed. Development of requirements and guidelines for physical infrastructure improvement (e.g., ramps and intersections). Exploration of most cost-effective solutions for (re-) design of ramps and intersections, and implementing pilots.

PI3: Road categorization ISAD levels also for digital and physical infrastructure	
General TransAID contribution	TransAID neither targets (re-)design of physical infrastructure, nor provides a comprehensive analysis of requirements for deploying CAVs. The scope of the project is to identify requirements for road infrastructure (related to scenarios to prevent, manage / support or distribute ToC/MRM), and to identify potential barriers for facilitating CAV implementations.
Relevant use cases and results	There is no specific TransAID use case targeting physical infrastructure. However, in general we agree with the research results of related projects on this topic, especially to estimate / detect future TAs in advance.
Important stakeholders and their role	**OEMs:** Collaborate with road authorities to develop ISAD levels in to a useful concept with relevant attributes w.r.t AD. **Road Authorities:** further develop the concept of ISAD levels and categorise and share the ISAD levels of the network. **Road Operators:** Maintain and update ISAD levels of the road network. **Service Providers:** Share ISAD levels with OEMs and validate against CAVs ODD to identify TAs. **Standardisation bodies:** Develop standards to define, maintain and exchange ISAD levels.
Stakeholder responses	Physical infrastructure is the basis of road transport and CAV deployment. Requirements for ISAD should be well defined and specifications need to be provided.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Further specification and official introduction of ISAD levels for digital and physical infrastructure.

2026-2030	Consideration of vehicle sensor evolution in further development of infrastructure specifications. Annual review of new roads design guidelines.
2031-2040	Consideration of vehicle sensor evolution in further development of infrastructure specifications. Annual review of new roads design guidelines.
Recurring questions	Is the physical infrastructure in my country, region, or city sufficient for supporting CAV deployment, e.g., at Level-3 and Level-4 respectively? What are the guidelines for improving road infrastructure? In case further investment is needed, what are the estimated costs for establishing an ideal physical infrastructure for supporting CAV deployment at Level-3 and Level-4 respectively? What additional attributes should be included in the ISAD levels concept such that CAVs can understand them? To what extend will OEMs be willing to be dependent on infrastructure for AD functions?
Ongoing, relevant and/or future research and innovation activities	Development of requirements and guidelines for physical infrastructure improvement. Exploration of most cost-effective solutions, and implementation of pilots.

4.2 Digital infrastructure

Digital infrastructure is the key component of the TransAID project. This includes appropriate sensors, but also appropriate "actors" like traffic lights and VMSs. The presence of sensors and actors on its own gains much more potential if it is combined with V2X infrastructure, since it allows cooperation between the different entities.

In TransAID, sensors, actors and the communication part in-between have been investigated in the light of TAs and the presence of CAVs. The following tables provide an overview on the used components and how they have been addressed:

- DI1: Roadside stations for short range V2I
- DI2: External indication of being driven by ADS, or being last in platoon to ensure safety & TM
- DI3: Use of digital twins for the (road) transport system
  - *AVs will detect and provide information on incidents, e.g., by detecting stopped vehicles and roadway defects*
- DI4: Digitalisation of incident and traffic management plans
  - *Digitalisation of traffic management centres*
- DI5: Digitalise traffic rules and regulations
  - *New infrastructure and regulations for traffic law enforcement, including for conventional vehicles*
- DI6: Standard AV-suitable communication protocols with TMC, fleet managers, service providers and automated vehicles
  - *Improving information quality*
  - *Quality assurance and assessment of data*
  - *AVs will detect and provide information on incidents, e.g., by detecting stopped vehicles and roadway defects*
- DI7: Provision of hybrid C-ITS traffic information services
- DI8: Sharing of data and storage of data
- DI9: Develop investment scenarios for road side systems vs smart vehicles. What is needed in light of evolution of automated vehicles?

DI1: Roadside stations for short range V2I	
General TransAID contribution	TransAID has proposed and evaluated the use of roadside stations with an active role to support traffic management and cooperative manoeuvres of CAVs with the final goal of increasing the overall traffic flow and safety, especially at TAs. To this aim, roadside stations can send advices / recommendations using V2I communication to specific vehicles individually to adapt their speed, headway, or lane, as well as to schedule Transitions of Control. In TransAID, roadside stations in some situations consist not only of ITS-G5 communication units, but also of sensors (e.g., cameras) and/or actors (e.g., VMS) which are directly coupled to it. In addition, roadside stations require computation power to convert the inputs into improvement measures.

Relevant use cases and results	In all the considered use cases, the roadside infrastructure plays a key role for the improvement of the traffic safety and efficiency thanks to the transmission of advices / recommendations that help manage TAs and schedule Transitions of Control (see sections 2.5.3 and 2.5.4). While communication is required in all use cases, the number and kind of sensors and VMSs is varying depending on the use case. One of the most important requirements in this light is the online / real-time detection of objects on the road and the related understanding which of the objects offer communication capabilities. In case several sensors are available, and especially in case vehicles share their plans (e.g., by sending MCMs), this also requires sensor data fusion. It is still very challenging to get an overview on the situation in real-time and to provide the related traffic management measures in time. This is especially true for highway merging (UC2.1) or for providing available safe spots (UC4.1+5.1).
Important stakeholders and their role	**OEMs:** Design automation and V2X communication systems that can process and –when appropriate- safely follow the advices provided by the road infrastructure manager through roadside stations according to vehicle state, road environment and surrounding traffic conditions, etc. CAVs need to be designed in a way fostering cooperation instead of following egoistic goals to allow system optima. The inclusion of standard conforming and updatable communication hardware is a key requirement. **Road Authorities:** Provide rules and guidelines for the deployment of road-side infrastructure based on their value towards safely and efficiently managing the traffic. Help in achieving a good sensor overview without harming GDPR, provide useful places for sensor and communication equipment. **Road Operators:** Deploy and maintain the road-side infrastructure. **Service Providers:** Implement and deploy services for managing TAs and Transitions of Control using the road-side infrastructure to interact with the vehicles. Correlate the measures to all other measures on the road, so that hardware can be used for several purposes at once (e.g., an RSU near a road works area may send incident information but may also be used for providing traffic measures in the area). **Standardisation Bodies:** Evolve existing V2X communication standards to define the messages and communication protocols needed to efficiently handle TAs and transitions of control using V2X communications. This can require extending existing V2X messages or define new ones when necessary.
Stakeholder responses	More than 60% of participants in the TransAID final event consider that the (digital) infrastructure support at TAs is “Essential”, and more than 30% consider it as “Nice to have”. Only 2% consider that is “Not really required”.

	At the TransAID final event, more than 80% of the participants consider that the best option to support manoeuvre coordination is through a combination of V2V and V2I/V2N options, depending on the scenario. The standardisation of the corresponding V2X messages to enable the participation of the roadside stations in the manoeuvre coordination is being conducted by ETSI and has not been finished yet. TransAID has made contributions to explain the benefits from the participation of roadside stations and to include the support of manoeuvre coordination protocols. Additional efforts will be needed for the inclusion of these messages in the final technical specification.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Specification of V2X messages to support a first set of services and use cases. Deployment of roadside stations in key locations and pilots. Potential use of cellular communication and sensor fusion technologies.
2026-2030	Evolution of existing V2X messages, services and use cases. Wider deployment of roadside stations. Evolution towards a hybrid V2X communication system with advanced messages and services.
2031-2040	Evolution towards more contextualised advices that consider the characteristics and context of each vehicle based on data fusion and artificial intelligence.
Recurring questions	Will it be likely that vehicles/OEMs follow the advices of the roadside infrastructure? What type of advices will need to be mandatorily followed and is such mandating feasible? How can infrastructure get a very detailed view on the road and on the plans of the vehicles without harming GDPR?
Ongoing, relevant and/or future research and innovation activities	Use of cellular communication technologies (including 4G LTE and 5G NR) to support traffic management and possibly replace and/or complement roadside stations. Use of artificial intelligence and data fusion for a closer interaction between roadside stations and vehicles.

DI2: External indication of being driven by ADS, or being last in platoon to ensure safety & TM	
General TransAID contribution	When vehicles perform ToCs and MRMs, the traffic system (in terms of e.g., efficiency and safety) is influenced in a negative way. Therefore, informing unequipped vehicles about traffic management measures especially in TAs can help to enlarge the positive impact of the measures. Since the different measures in the use cases require different approaches of getting the necessary information to the unequipped road users, different technologies should be used.

	Here, TransAID investigated the potential of using VMSs in such areas. Although HMI is not a TransAID topic, some initial studies have also been performed investigating the potential of a CAV external LED light strip, which is indicating the current automation capabilities as well as ToC and MRM information. Such a vehicle-centric system can improve the understanding of the ongoing situation and therefore lead to higher performances of drivers of unequipped vehicles in the vicinity of the CAV currently having issues.
Relevant use cases and results	All use cases have been investigated and guidelines for possible information strategies to unequipped road users have been given. In most cases, the combination of VMS and CAV external LED light strip have been rated most promising (see TransAID deliverable D5.4). Both offer the ability of flexible and dynamic warnings. Using an LED light strip on the exterior of a CAV will create a much better understanding of CAV behaviour, since the standard lights are not sufficient (e.g., in case of an MRM stopping using the emergency indicators while trying to indicate a lane change in parallel). Nevertheless, additional research is required.
Important stakeholders and their role	**OEMs:** It could be very valuable if OEMs communicate the currently driven automation performance / capabilities also to surrounding vehicles, especially in case of ToCs and MRMs. This could improve the situation awareness of drivers in the vicinity and therefore reduce safety critical situations. However, they would need to study the balance between the degree of distraction to surrounding vehicles / drivers vs. the added information (i.e., usefulness vs. information overload). **Road Authorities:** Provision of updates of the messages on road, e.g., speed limit and VMS. **Road Operators:** Deploy and maintain the road-side infrastructure. **Service Providers:** Implement and deploy the service for flexible, dynamic and fast responding VMS content in line with the traffic management measure. **Standardisation Bodies:** Provide easy to understand and standardised signage for the different use cases and related situations. This includes a proper signage allowing the addressing of CAVs, e.g., “lane for CAVs only”, etc. Standardisation of external communication of CAVs is also required, e.g., content and positioning of LED light strips. This includes, e.g., definition of proper colours for LED communication. In several research projects, the colour blue has been used to indicate AD. When this colour is used as external LED light colour, it will easily be confused with the lighting of emergency vehicles.
Stakeholder responses	In the TransAID symposium, more than 85% of the participants say that OEMs should explain the limitations of their vehicle automation. At the TransAID-INFRAMIX stakeholder workshop more than 52% indicated that non-automated vehicles should be informed when AVs in their vicinity behave differently in order to optimise traffic flows / create safer conditions. More than 31% are unsure and 16% neglect.

Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Research and innovation to identify best solutions; pilots with evaluation; drafting of specifications.
2026-2030	Standardisation and mandating.
2031-2040	Use standardised approaches.
Recurring questions	In case of external communication of CAV automation capabilities and activations, this information may also be misused. How can this be avoided? Does the external communication of CAVs distract other drivers too much from the driving task? What is the best way to show and explain the behaviour of CAVs with different capabilities to surrounding unequipped vehicles? Is there the need to distinguish different CAV capabilities on signs (e.g., “not allowed for AVs, but CAVs are allowed”)?
Ongoing, relevant and/or future research and innovation activities	The question of external lights of CAVs has been touched by several research projects, yet no consensus or further standardisation has been started.

DI3: Use of digital twins for the (road) transport system *Additional related actions:* *AVs will detect and provide information on incidents, e.g., by detecting stopped vehicles and roadway defects*	
General TransAID contribution	To get a very detailed overview on current road situations, it is required to digitally model the road network and the capabilities of each entity, being a vehicle, a traffic light/VMS, a sensor or communication device. This is the key requirement for achieving optimality. In TransAID, traffic measures are related to vehicle capabilities and the percentage of CAVs in the traffic system. Without knowing these details, best including ODDs of each CAV individually, it is hard to find the relative system optimum in terms of efficiency and safety. In TransAID, the traffic management measures implemented as real-world prototypes included digital twins of the environment and the vehicles to provide the ideal traffic management measure. Here, not all details of each entity were used. It was focussed on communication and automation capabilities, plus positions, dimensions, and speeds of all detected road users.
Relevant use cases and results	Although digital twins are important in all TransAID use cases, there is a high relevance in highly dynamic use cases (e.g., highway merging) and in

	TAs in general, as infrastructure needs to estimate if a vehicle can pass an oncoming situation or not.
Important stakeholders and their role	**OEMs:** It is required to identify a way of providing the ODDs of individual CAVs to other entities, without harming OEMs' interests and without harming GDPR. **Road Authorities:** Provide digital twins of the road networks and available sensors. Provide infrastructure which is able to detect and track unequipped road users, so that the creation of digital twins becomes possible. **Road Operators:** Update states of infrastructure components in the digital twins. **Service Providers:** Merge the given information of the other entities and use it to provide optimal traffic management measures. **Standardisation Bodies:** Provide ways of exchanging ODDs and data of other related parties in a flexible way. It is important to identify common interfaces to avoid numerous individual approaches. This includes data content, quality and rights management.
Stakeholder responses	At the TransAID final event, 73% voted that ODD definitions should be openly available, while 23% voted that this information shall be treated confidential and accessible for specific entities only. The ODD information should be shared by using a centralised database (48%) or by constant broadcasting of the capabilities (44%).
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Integration of key automation concepts ODD, ISAD and information provision tools (HD Map) under the umbrella concept of the digital twin for the road transport system, prototypes demonstrating the viability, pilots starting.
2026-2030	Piloting at larger scale, operating models ready for deployment.
2031-2040	Deployment and use, including adaptations.
Recurring questions	How can ODD data be shared without revealing OEMs IPR? What are the required parameters (number & definition) to fulfil digital twins needs?
Ongoing, relevant and/or future research and innovation activities	For sharing ODDs, possible formats are currently discussed e.g., at ASAM (OpenODD) and ISO. In addition, the recent 2020 CEDR call for proposals poses several questions regarding the ODD and ISAD concepts.

DI4: Digitalisation of incident and traffic management plans *Additional related actions:*

Digitalisation of traffic management centres	
General TransAID contribution	Incidents on the road are one main cause for TAs, and directly affect traffic management. The same is true for the presence of no-AD-zones. In order to cope with such incidents, corresponding plans (e.g., in line with the TransAID traffic management measures) should be available, to allow a flexible and fast reaction.
Relevant use cases and results	All TransAID use cases require a flexible reaction to road situations, including incidents. But there is a difference in the respective time frame of the scenarios. Some no-AD-zones (e.g., tunnels) are static and could be handled with long planning periods. Others are semi-static (e.g., construction sites) and can mostly be planned in advance. Most critical are the very dynamic situations (e.g., broken-down vehicles, floods) which require very urgent reaction and therefore readily and in advance developed plans. For this, it is important that there is a known basis for the plan development, which can only be achieved when, e.g., ODDs, ToC and MRM events and vehicle incidents related to TAs are reported, e.g., in a commonly available database.
Important stakeholders and their role	**OEMs:** To allow the development of plans, CAV restrictions and ToC/MRM events need to be reported. OEMs should make such ODD limitations and events openly accessible. **Road Authorities / Road Operators:** Provide data on known incidents and planned road limitations, e.g., road works. **Service Providers:** Develop plans for the different scenarios, including static, semi-static and dynamic reactions. **Standardisation Bodies:** Establish common interfaces for the exchange of ODDs and ToC/MRM reports, and foster the creation of commonly available databases.
Stakeholder responses	At the TransAID final event, 73% voted that ODD definitions should be openly available, while 23% voted that this information shall be treated confidential and accessible for specific entities only. The ODD information should be shared by using a centralised database (48%) or by constant broadcasting of the capabilities (44%). Furthermore, 77% (primarily road authorities and academia) voted that AD disengagements should be mandatorily reported from OEMs to road authorities by using an open standard.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Standardisation of interfaces to common databases and protocols to exchange traffic management procedures.
2026-2030	Implementation of interfaces at all stakeholders.
2031-2040	Generation of plans and deployment.

Recurring questions	How can ODD data be shared without revealing OEMs IPR? Depending on the ODDs of CAVs, it needs to be defined which other sources of data need to be included to generate TM plans. This may include weather stations, incident reporting by the police, etc. It is unclear how much data needs to be included to generate good TM plans.
Ongoing, relevant and/or future research and innovation activities	Besides the standardised definition of ODDs (e.g., ASAM OpenODD), also common frameworks for exchanging data are required. In Germany, the large initiative GAIA-X has started working on this topic which will soon be launched for Europe.

DI5: Digitalise traffic rules and regulations *Additional related actions:* *New infrastructure and regulations for traffic law enforcement, including for conventional vehicles*	
General TransAID contribution	AD is based on applying traffic rules and traffic regulations to AVs, in order to behave similar or better than human drivers. In case of speed limits and no-passing zones this is simple, but in case of way-of-right it is already much more difficult, as it often implies a proper detection of road types and road users of different and possibly changing priorities. Furthermore, way-of-right situations deviate in different countries. But it gets even more complicated when thinking about situations where human drivers need to bend traffic rules, e.g., in case a broken-down, a service vehicle blocking a single lane in a no-passing zone, or when the only right-turn lane at an intersection is blocked by an incident. In these cases, human drivers are not behaving according to the general traffic rules to not get stuck. AVs cannot easily do the same, as therefore it needs to be clear that this is the only possible option. Intelligent road side infrastructure may have the required overview to properly allow such cases. Both, CAV behaviour and dynamic RSI advice is based on digitalised traffic rules and regulations.
Relevant use cases and results	While digitalisation of traffic rules and regulations is a key requirement of AD itself, it is also a required part for intelligent RSI advice. This is true for all TransAID use cases. Nevertheless, the precise advice to behave different than the physical infrastructure is indicating (e.g., TransAID use cases 1.1, 1.3, 2.3 and 4.2) also requires a clear statement of respective liability. Use cases 1.1, 1.3, 2.3 and 4.2 all contain situations where behaviour is required that conflicts with the rules of the ‘normal’ situation. In UC1.1 one needs to drive via a bus lane and in UC1.3 via the emergency lane. Use case 2.3 requires the vehicle to take a right turn from a lane from which it is normally not allowed and UC4.2 requires a stop in an area which is not available in the normal situation.

Important stakeholders and their role	**OEMs:** Share information about system limits, e.g., being part of ODD descriptions. Engage with road authorities, road operators and service providers to create a common understanding of services. **Road Authorities:** Clearly define in which cases infrastructure is allowed to bend traffic rules and regulations, and which limitations exist. Help to reduce situations requiring the bending of traffic rules, e.g., by clearing unnecessary road signage or by providing additional room to pass such situations where possible. Engage with OEMs to create a common understanding of services. **Road Operators:** Help to reduce situations requiring the bending of traffic rules. Send information and advices to vehicles and make sure traffic conditions remain safe with respect to the effect of the information / advices. **Service Providers:** Create a database of all signs and apply all traffic rules to the given set of roads in order to detect possible bottlenecks and to define proper countermeasures. **Standardisation Bodies:** Help to define proper quality standards to allow infrastructure advice and CAV reaction also in critical situations which require bending of traffic rules and regulations. Develop liability frameworks.
Stakeholder responses	At the TransAID final event, 77% voted that CAVs should be able to break the law to behave similar to human drivers (7% voted that CAVs should do this based on their own judgement, 70% voted to allow this in a regulated context). On the other hand, 22% voted that this should not be allowed, under no circumstance. U.S. OEMs are very hesitant when considering V2X infrastructure support for AD. Cross-country differences complicate liability frameworks because of differences in the legal landscape. It was often acknowledged that there is the need to adapt traffic rules for automation, for example, to differentiate speed / relevance areas for different categories of vehicles. Infrastructure must be authorised by road authorities to provide advices to vehicles (that possibly bend traffic rules) in a fast and dynamic way or be mandated for recurrent situations.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Pilots to investigate collaboration between infrastructure and OEMs. Cooperation between OEMs and road authorities to harmonise the need and understanding of information provided to vehicles. Start working on governing / regulatory frameworks covering accountability.

2026-2030	Continue working on governing / regulatory frameworks covering accountability.
2031-2040	Continue working on governing / regulatory frameworks covering accountability.
Recurring questions	Who is liable if infrastructure advises to ignore traffic rules? The whole aspect of accountability: who is responsible for what, is in general a recurring question. A more specific related question is: to what extent will OEMs allow their cars to be dependent on information from external sources?
Ongoing, relevant and/or future research and innovation activities	The EU FP7 AdaptIVe project has looked into legal questions resulting from automation. The project lex2vehicle - bring traffic laws to the end user – is researching how traffic laws can be followed by AVs (https://lex2vehicle.com/). German project PAcT (Proving Accountability in Traffic): Technical University of Munich is investigating how laws can be formalised to be approved by software automatically.

DI6: Standard AV-suitable communication protocols with TMC, fleet managers, service providers and automated vehicles *Additional related actions:* *Improving information quality* *Quality assurance and assessment of data* *AVs will detect and provide information on incidents, e.g., by detecting stopped vehicles and roadway defects*	
General TransAID contribution	TransAID has contributed to the standardisation of V2X communication protocols for collective perception and manoeuvre coordination that support connected AD. They enable the exchange of information about detected objects (V2V and V2I/I2V) and the exchange of messages to coordinate the driving manoeuvres (V2V and V2I/I2V). We have proposed message generation rules that dynamically adapt to the vehicle / traffic context and have evaluated them in combination with ETSI's congestion control protocols to assess their scalability. In addition, we have proposed methods to reduce the transmission of sensor information by CAVs that improve the scalability of the underlying vehicular networks. TransAID has also proposed and evaluated for the first time the use of data compression algorithms to reduce the channel load generated by V2X messages. These algorithms would be used at the transmitter to compress each message before it is sent down through the communication protocol stack. At the receiver, they would decompress each message to

Relevant use cases and results	All the use cases considered in TransAID benefit from an improved knowledge of the surrounding environment thanks to the collective perception solutions proposed. The collective perception protocols proposed in TransAID reduce the channel load up to 40%-50% and improve the object detection around 10% compared to the ETSI solution. The two protocols proposed in TransAID are now part of the ETSI TR (Technical Report) and TS (Technical Standards) about collective perception. All the use cases considered, employ the V2X message flows proposed for manoeuvre coordination. The proposed solutions can significantly decrease the radio channel load (between 50% and 80%) compared to a 10 Hz constant V2X message transmission policy, while maintaining the performance of the manoeuvre coordination. We have also shown that data compression has the potential to reduce the channel load up to 27% without reducing the amount of information transmitted. However, the conducted study also emphasises the need for high-speed compression and decompression modules capable to compress and decompress V2X messages in real time, especially under highly loaded scenarios.
Important stakeholders and their role	**OEMs / Road Authorities / Road Operators / Service Providers:** Adopt standardised V2X communication protocols designed for safer and more efficient CAVs. **Standardisation Bodies:** Design efficient and scalable V2X communication protocols that can support CAVs services and the increasing V2X communication demands of CAVs.
Stakeholder responses	There is recurring consensus regarding the need for connectivity to support AD to extend the ODD and enable cooperation between vehicles and infrastructure which leads to higher safety, efficiency, and comfort.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Deployment of communication protocols that focus on awareness driving based on the vehicle's status data. Design and specification of next generation of V2X standards.
2026-2030	Deployment of communication protocols for connected and automated driving that exploit sensor data at the CAVs and the road infrastructure.
2031-2040	Deployment of communication protocols that focus on cooperative driving based on coordination and intention data.
Recurring questions	What is the impact of communications latency and reliability on traffic safety and efficiency?
Ongoing, relevant and/or future	The deployment of advanced V2X services (Day 2 and Day 3+) will require more than one radio channel and solutions that exploit multiple channels will be required. UMH is now working in ETSI's STF (Special Task Force)

research and innovation activities	585 for the design of a set of specifications that enable the use of multiple channels for the deployment of advanced V2X services.

DI7: Provision of hybrid C-ITS traffic information services	
General TransAID contribution	The V2X solutions designed in TransAID are technology agnostic. The proposed communication protocols and V2X messages are defined at the Facilities layer of the protocol stack. Therefore, they could be used on top of any wireless technology (e.g., ITS-G5, LTE-V2X or 5G NR V2X) as well as in hybrid V2X deployments.
Relevant use cases and results	The C-ITS solutions designed based on V2X communications and the use of roadside stations have shown a high potential to support the TransAID use cases and improve the communications performance and efficiency. Since the proposed solutions are technology agnostic, they could be applied to, e.g., LTE-V2X (or C-V2X) or 5G.
Important stakeholders and their role	**OEMs / Road Authorities / Road Operators and Service Providers:** Implement technology agnostic solutions that do not depend on the underlaying wireless technology and are valid for hybrid deployments. **Standardisation Bodies:** Enable hybrid communication system scenarios through the development of the necessary specifications.
Stakeholder responses	In the TransAID final event, 65% of the participants consider that a hybrid connectivity solution will be required for some levels of automation (e.g., L3 and higher). Interestingly, 15% considered that ITS-G5 would be sufficient and another 15% considered that cellular 4G/5G would be enough.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Deployment of Day-1 awareness-based and notification-based services.
2026-2030	Deployment of Day-2 services for connected vehicles and AVs, including services facilitating the coexistence of conventional vehicles and CAVs.
2031-2040	Deployment of Day-3+ services leveraging the full potential of CAVs and exploiting AI (Artificial Intelligence) with fusion of sensor data at the road infrastructure to support richer knowledge of the driving environment and a more dynamic and personalised interaction between road infrastructure and CAVs.
Recurring questions	What is the best and most suitable wireless communication technology? How to manage hybrid communications solutions?
Ongoing, relevant and/or future	ETSI has recently published TR 103 576-2, a pre-standardisation study on ITS architecture to support interoperability among heterogeneous ITS

research and innovation activities	systems and backward compatibility. The TS (Technical Specification) will be designed using this TR as a basis.

DI8: Sharing of data and storage of data	
General TransAID contribution	The availability of more data and the sharing of data in general are very important aspects to cope with TAs. It is required to know under which conditions, and at which places vehicle automation functions are going to fail. This requires data from all stakeholders which needs to be shared and combined, starting from ODD data of the OEMs, to road and lane attributes, communication capabilities, availability of road sensors and traffic signage, quality of services, etc., but even weather conditions (e.g., fog, blinding lights) and incidents on the road.
Relevant use cases and results	The sharing of data is a key requirement of all TransAID use cases. The combination of sensors, VMSs, and communication technology in the TransAID services shows this clearly. It is important to mention that the quality of the traffic management service will be better if more data is available. To achieve this goal and to avoid too many individual interfaces, it is important to standardise interfaces and to develop digital ways of sharing the data online without creating GDPR issues.
Important stakeholders and their role	**OEMs:** Provide ODD definitions of vehicles and provide information about ToC/MRM requirements (e.g., parameters of supported safe spots, possible decelerations) as well as data about positions and causes of ToCs/MRMs. **Road Authorities / Road Operators:** Provide data on all aspects of the road, including lane parameters, communication, sensors, actors (e.g., traffic lights, VMS), signal plans, etc. (i.e., ISAD levels). **Service Providers:** Depending on the kind of the provided service, this includes the sharing of additional data and the merging of existing data to generate traffic management measures. **Standardisation Bodies:** Define common interfaces for data exchange, including GDPR and IPR handling as well as quality of data and liability.
Stakeholder responses	At the TransAID final event, 73% voted that ODD definitions should be openly available, while 23% voted that this information shall be treated confidential and accessible for specific entities only. The ODD information should be shared by using a centralised database (48%) or by constant broadcasting of the capabilities (44%). Furthermore, 77% (primarily road authorities and academia) voted that AD disengagements should be mandatorily reported from OEMs to road authorities by using an open standard.
Timeline	*Below recommended steps are provided given different time horizons.*

2021-2025	Definition of common interfaces, standardisation, creation of databases and inclusion of first data sets. Pilots starting.
2026-2030	Implementation of interfaces according to the defined interfaces. Creation of data merging services. Large scale pilots.
2031-2040	Further deployment and use, incl. adaptations.
Recurring questions	How can companies, especially OEMs, be motivated to share their data openly? How can misuse of data be limited? How can IPR and GDPR always be respected?
Ongoing, relevant and/or future research and innovation activities	Besides the standardised definition of ODDs (e.g., ASAM OpenODD), also common frameworks for exchanging data are required. In Germany, the large initiative GAIA-X has been started working on this topic which will soon be launched for Europe.

DI9: Develop investment scenarios for road side systems vs smart vehicles. What is needed in light of evolution of automated vehicles?	
General TransAID contribution	TransAID results show the need of traffic management including smart vehicles and smart roadside to allow AD under several circumstances. As previously stated, the sharing of data plays a major role here. But in the light of investment scenarios, it is difficult to start the process. Companies need to safeguard their IPR, although it is already commonly known how powerful the aggregation of data can be (see e.g., Google, Facebook, etc.). Currently, it is not known how data of several companies can be shared and merged without harming IPR or GDPR, and often companies hesitate to provide data which may be useful for their own business in the future. Therefore, it is important to: a) Create a common platform which allows sharing of data without harming IPR/GDPR. b) Create common interfaces to avoid the necessity of developing several interfaces at each company. c) Provide incentives to companies to share their data, especially in the beginning. d) Study the concept of trusted third parties as intermediary roles (as introduced in section 2.6) that process the data under strict agreements to support needed services. Although TAs are currently a futuristic topic, they nevertheless will occur and impact the traffic systems when the number of CAVs/AVs is rising. It is important to claim investments already now since Sustainable Urban Mobility Plans (SUMP) are set up defining long-term investments.

Relevant use cases and results	All TransAID use cases, and even unforeseeable future TA cases will require exchange of data as well as smart infrastructure combined with smart vehicles. Therefore, corresponding business models are required to allow proper handling of TAs. TransAID deliverable D9.6 reports on some ideas for these models, particularly the trusted third party as an intermediary concept.
Important stakeholders and their role	**OEMs / Road Authorities / Road Operators / Service Providers:** Provide as much data as possible (considering the issues mentioned above) and take part in pilot projects. **Standardisation Bodies:** Foster standardisation of common data exchange formats and platforms.
Stakeholder responses	At the TransAID final event, 42% voted that cities / road authorities should use budget for automation readiness best to equip roads / intersections with communication technology, followed by 35% for the equipment with sensors. In addition, 12% voted for using the budget to categorise roads according to ISAD levels, and another 12% to enhance the quality of roads in general.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Standardisation of interfaces to common databases.
2026-2030	Implementation of interfaces at all stakeholders.
2031-2040	Deployment and use.
Recurring questions	How can it be made more profitable for companies to share their data, especially in the beginning? Is investment first done at vehicles or at infrastructure? How can it be guaranteed that an investment is paying off in such futuristic scenarios?
Ongoing, relevant and/or future research and innovation activities	Common frameworks for exchanging data are required. In Germany, the large initiative GAIA-X has been started working on this topic which will soon be launched for Europe. H2020 CoEXist worked on automation readiness and a SUMP 2.0.

4.3 Traffic management

Vehicles with different automation and connectivity capabilities are gradually entering the vehicle fleet. The AD functions of the latter vehicles have different ODDs and are expected to disengage and handover control (back) to the driver/(remote) operator due to internal system failures or challenging situations (e.g., traffic, environmental, road maintenance etc.) encountered in the road environment. Thus, there will be a transitional period on the roads characterised by heterogeneous traffic behaviour and control transitions. Moreover, control transitions are expected to induce significant traffic disruption especially when they result in minimum risk manoeuvres. Therefore, traffic management strategies that utilise state-of-the-art C-ITS services and are tailored to the needs of mixed traffic are essential for enabling safe, efficient and climate neutral traffic operations. Infrastructure can play a pivotal role to the latter end via the provision of personalised instructions to CAVs that can prevent, manage, or distribute control transitions caused by complex situations on the road. Six different actions relevant to infrastructure-assisted traffic management of control transitions are analysed in-depth in the tables below which consider the topics:

- TM1: Safe minimum risk manoeuvre specification considering also cases of very large AV fleets
- TM2: Supply real-time information on road status and regulations
- TM3: Joint deployment of infrastructure-assisted traffic management and cooperative driving
- TM4: Deployment of geofencing for traffic management
- TM5: Real-time lane management
    - *Consider criteria for dedicated lanes*
- TM6: Prepare to invest to support the ODD but be very selective

TM1: Safe minimum risk manoeuvre specification considering also cases of very large AV fleets	
General TransAID contribution	TransAID modelled, simulated, implemented, and tested different possible features and variants of MRM. We assumed that during MRM the driver-vehicle can exhibit the following behaviour: a. CAVs decelerate with constant deceleration before finally stopping. b. Automated lane changing to any desired lane is possible. c. Drivers can resume control prior to full vehicle stop. d. CAVs continue driving at cruise speed[6] when they are aware of a safe spot location. Right before the safe spot, they perform the actions at point a. Simulation analysis was conducted that compared unmanaged MRM taking place in lane with guided MRMs (infrastructure-assisted) that brought CAV to full stop at safe harbours / safe spots (e.g., on the emergency lane). Moreover, focus was placed on the management of multiple MRMs (heuristic for assessing and targeting available safe harbours / safe spots) occurring concurrently in narrow spatial domain and temporal window.

[6] There was some discussion if this should be 'cruise speed' or 'reduced speed'. In the end it is likely the implementation depends on the OEM and perhaps even the exact scenario.

	Field operational tests compared infrastructure-assisted MRM management that provides relevant information to guide CAVs to safe spots with an unmanaged / baseline approach in which CAVs may perform safe MRM if it discovers it while decelerating (otherwise it stops on the driving lane).
Relevant use cases and results	Specification, impact assessment and management of MRMs was conducted in the context of UC4.2 "Safe spot in lane of blockage & Lane change Assistant" and UC4.1+5.1 "Distributed safe spots along an urban corridor". In UC4.2, MRM taking place in lane was compared with MRM guided towards safe harbour, while in UC4.1+5.1 a mechanism for assigning multiple MRMs to several available safe harbours was evaluated. Findings from the analysis of both UCs indicate that preventing MRMs from occurring in lane via infrastructure assistance significantly improves traffic efficiency, safety and environmental KPIs. Proof-of-concept field testing of UC4.1+5.1 demonstrated that infrastructure-assisted MRM management always (under the tested conditions) succeeded in guiding CAVs to a safe spot to park, prevented CAVs blocking or stopping on driving lanes, prevented CAVs from having to drive at low speeds and therefore improve the safety of MRMs for the CAVs as well as for surrounding traffic. In addition, an MRM warning using an external LED light strip mounted on CAVs was examined in TransAID deliverable D5.4. This external HMI was rated useful in a performed VR study, although a more detailed analysis and additional standardisation activities to avoid different approaches are required (Schindler, et al., 2020).
Important stakeholders and their role	**OEMs:** Design automation systems that can safely execute MRM according to vehicle state, road environment and surrounding traffic conditions. Develop communication, map matching and automation control capabilities on the vehicle side to harness infrastructure advice about safe harbours and enable cooperation with surrounding traffic that will facilitate safe arrival at safe harbour. Establish mechanisms to let the infrastructure be aware of MRM relevant information (e.g., the leading time before an MRM occur), as the infrastructure can use this information for a more accurate assignment of ToC and safe spot advices. **Road Authorities:** Provide rules and guidelines with respect to proper demarcation of safe harbours and deployment of road-side side infrastructure that can assist MRM guidance. **Road Operators:** Establish and monitor safe harbours. Deploy road-side infrastructure that can assist MRM guidance. **Service Providers:** Develop services that enable MRM guidance towards safe harbours under complex road traffic conditions. **Standardisation Bodies:** Develop standards with respect to safe harbour demarcation and signage, as well as communication standards to support I2V advice for MRM guidance to safe harbours.

Stakeholder responses	An MRM cannot be defined in an absolute manner. It is context dependent (depends on both the actual situation (context) and the available information (contextual awareness)). Moreover, an MRM features and performance can be reason for competition among OEMs. MRMs are highly likely to differ between expected and unexpected transitions of control. Drivers should be allowed to take-over vehicle control during MRM. In lane MRM should be prevented for safety critical issues.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Specification of MRM per automation UC. Pilots on key highway, peri-urban and urban areas.
2026-2030	Harmonised specifications for common key aspects of MRM functions, physical and digital infrastructure. Deployment in key highway, peri-urban and urban areas.
2031-2040	Deployment and use; constant adaptation of specifications.
Recurring questions	Is MRM part of the ODD or not? Which stakeholders should have a role in formulating acceptable and safe MRMs? Which elements should be taken into consideration when describing MRM within specific contexts? What are allowable MRM actions in cases where a CAV does not possess perfect knowledge of the context (traffic situation)? How to deal with every OEM having its own MRM solutions?
Ongoing, relevant and/or future research and innovation activities	The safety implications of different MRM implementation types (e.g., preferred deceleration rates, keeping the current cruise speed or not if a safe spot location is known, etc.) are currently being assessed mostly via simulations. Additionally, focus is placed on the investigation of different systems that can increase anticipation of MRMs by other road users. There is limited research in the field of infrastructure-assisted management of MRMs though. Field testing of MRMs in the context of different automation level use cases is necessary prior to wide deployment.

TM2: Supply real-time information on road status and regulations	
General TransAID contribution	TransAID developed traffic management plans for mixed traffic that account for events (planned and unplanned) which affect road status and traffic operations respectively, and traffic situations when relaxation of traffic regulations can prevent ToC/MRMs from the CAV side.

	The latter plans not only provide real-time information about the road status (e.g., closed lanes due to road works) to CAVs (via dedicated C-ITS messages) and LVs (via conventional signalling methods), but they also offer real-time advice (e.g., lane change / keep advice, proactive ToC, path information etc.) to address the challenging traffic situations by either preventing or managing ToCs/MRMs. Moreover, they indicate preferable actions (e.g., use of emergency lane upstream of off-ramp) when traffic regulations need to be relaxed so that negative impacts of ToCs/MRMs can be avoided.
Relevant use cases and results	Scheduled events (i.e., road works) that affect road status and can induce ToCs/MRMs were considered in the context of UC1.1 "Prevent ToC/MRM by providing vehicle path information" and UC4.2 "Safe spot in lane of blockage & Lane change Assistant". In the context of UC1.1 road works blocked two general purpose lanes leaving open only one bus lane. The TMC provided real-time path information to CAVs so that they could use the bus lane to cross the road works without executing ToCs. Simulation results indicated that the proposed traffic management plan generates significant traffic safety benefits but not traffic efficiency ones. Similarly, road works blocked one general purpose lane on a two-lane road segment (both urban and motorway driving conditions were considered) in the context of UC4.2. The TMC proactively warned CAVs about the presence of road works and issued lane change / keep advice, proactive ToC advice, and provided enhanced perception in the proximity of the road works area to minimise the effects of ToCs/MRMs. Significant traffic efficiency and safety benefits were observed for motorway traffic conditions from relevant simulation experiments. Improvements in terms of traffic efficiency and safety were also observed for real-time traffic management due to lane closure from incident in the vicinity of signalised intersection (UC2.3 "Intersection handling due to incident"), as well as relaxation of traffic regulations (i.e., use of emergency lane by CAVs) near motorway off-ramp (UC1.3 "Queue spillback at exit ramp"). For both use cases, the TMC provided timely advice to arriving CAVs to inform about changed road status and looser traffic regulations in order to alleviate undesired traffic impacts from ToCs/MRMs. Finally, information regarding no-AD zones was supplied to CAVs in UC5.1 "Schedule ToCs before no-AD zone". Traffic regulations might prevent AD in certain areas in which case it is beneficial to spread ToC events in space and time.
Important stakeholders and their role	**OEMs:** Develop CAVs that can comprehend and enact upon advice and information provided by the TMC side. The CAVs shall ultimately take their own decisions based on current situations by following the advices if these do not imply safety risks (this is particularly meaningful when advices pertain to relaxation of traffic regulations). **Road Authorities:** Indicate traffic situations when traffic regulations could be relaxed to prevent ToCs/MRMs.

	Road Operators: Establish, support, and maintain physical and digital infrastructure necessary for the provision of real-time advice to mixed traffic about road status and traffic regulations. **Service Providers:** Develop services that provide real-time advice to CAVs with respect to road status and traffic regulations. **Standardisation Bodies:** Develop communication standards to empower I2V advice with respect to road status and traffic regulations.
Stakeholder responses	Local traffic regulations should be digitised and made available through end user services. Relying on advices provided by the road infrastructure and implement them as an additional control input is introducing an unprecedented scenario where it is not clear where liability might reside in case of system misbehaviour. European and Japanese stakeholders firmly defend the use of infrastructure support for AD and even highlight the need to adapt traffic rules for automation or change the legal frameworks (e.g., authorise the road infrastructure to provide advices that break the traffic rules if needed). On the contrary, US stakeholders are very hesitant and fear possible financial consequences resulting from liability issues.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Digitisation of traffic rules. Address liability issues. Standardisation. Studies and Pilots.
2026-2030	Pilots and demonstration in public roads (i.e., key peri-urban areas)
2031-2040	Deployment and use.
Recurring questions	Should infrastructure be authorised by road authorities to provide advice that bends traffic rules (in a fast-dynamic way or mandated for recurrent situations)? Where does liability of adopting / implementing an advice lie (and therefore the responsibility as well)? Can liability be different on a case-by-case basis?
Ongoing, relevant and/or future research and innovation activities	TransAID is rather unique in addressing ToC / MRM in and around TAs and no other initiatives are known at the time. Existing Day 1 C-ITS services can warn CAVs about imminent hazardous locations on the road. However, prevention or management of ToCs/MRMs in the vicinity of TAs requires the provision of TMC instructions that are tailored to the needs of individual CAVs. Thus, it is necessary to develop services and connectivity capabilities that can address the latter requirements soon. Moreover, focus should be also placed on the digitisation of traffic rules. The project lex2vehicle - bring traffic laws to the end user – is researching how traffic laws can be followed by AVs (https://lex2vehicle.com/). In addition, the German project PAcT (Proving Accountability in Traffic):

	Technical University of Munich is investigating how laws can be formalised to be approved by software automatically. Conduct studies that shall identify traffic situations when relaxation of traffic regulations could benefit mixed traffic by preventing the occurrence of ToCs/MRMs.

TM3: Joint deployment of infrastructure-assisted traffic management and cooperative driving *This is a specific TransAID action and not covered by one of the EU EIP/MANTRA actions*	
General TransAID contribution	TransAID proposed two approaches for enabling cooperative lane changing between CAVs. A distributed approach when CAVs initiate, negotiate, and implement cooperative lane changing without the participation of TMC, and a centralised one when TMC coordinates the trajectories of CAVs in the execution of the cooperative lane change. In the latter case, CAV cooperation can yield favourable conditions for surrounding traffic as well, since TMC possesses enhanced perception about prevailing traffic conditions. Moreover, TransAID specified the Manoeuvre Coordination Message (MCM) and necessary message flows considering both approaches. A preliminary analysis of MCM generation rules was also conducted.
Relevant use cases and results	The distributed cooperative lane changing approach was investigated in the context of UC4.2 “Safe spot in lane of blockage & Lane change Assistant”. Specifically, it was jointly deployed with infrastructure-assisted traffic management (i.e., lane change / keep advice) upstream of lane drop locations (i.e., road works). Simulation findings indicated that in the case of a fully connected and automated road environment traffic flow breakdown can be prevented even when traffic demand is high. Additionally, significant improvements were also observed with respect to safety and environmental KPIs.
Important stakeholders and their role	**OEMs:** Design and manufacture CAVs equipped with cooperative driving functions and relevant communication capabilities (for both the distributed and centralised approach). The CAVs shall ultimately take own manoeuvring decisions based on current situations by following the advices if these do not imply safety risks (this is particularly meaningful for situation in which the infrastructure might centrally coordinate manoeuvring but not detect risks in the close surrounding of vehicles). **Road Operators:** Deploy digital infrastructure that can support cooperative driving in a centralised way. **Service Providers:** Develop services that support cooperative driving in a centralised way. **Standardisation Bodies:** Develop communication standards for cooperative driving.

Stakeholder responses	Stakeholders support the idea of CAV cooperation with both other CAVs and Infrastructure. It enables a degree of vehicle management (both by the AD system and via information form infrastructure) otherwise impossible.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Standardisation of communication protocols. Development of automation functions with cooperative driving capabilities. Pilots.
2026-2030	Piloting in larger scale. Adaptation of protocols and cooperative driving functions. Wider deployment of digital infrastructure.
2031-2040	Deployment and use. Constant adaptation of specifications.
Recurring questions	How can digital infrastructure assist CAVs in merging sections? To what extent will OEMs allow their cars to be dependent on information from external sources?
Ongoing, relevant and/or future research and innovation activities	Ongoing research primarily focuses on the examination of cooperative manoeuvring on a use case basis. Emphasis has been already placed on cooperative lane changing, cooperative merging, platooning, autonomous intersection control and other scenarios. Moreover, distributed approaches have been favoured so far with respect to the latter use cases. Future research should address manoeuvre coordination considering a generic hybrid approach that utilises advantages from both distributed and centralised approaches. Relevant communication protocols should be also developed. ETSI's work on the MCS is of particular interest.

TM4: Deployment of geofencing for traffic management	
General TransAID contribution	TransAID did not explicitly consider geofencing for traffic management but developed traffic management plans that can manage ToCs/MRMs at the borders of geofenced areas. Specifically, the latter plans can jointly distribute ToCs in space and time upstream of a no-AD zone, while also guiding CAVs to safe harbours in case of MRMs (before or within the geofenced area depending on the deployment of the plan / service). In case preventing ToCs is not possible, the TMC could also 'deploy' a no-AD geofence around the TA and support traffic with a distribution of resulting ToCs in time and space, and possibly guide CAVs to safe spots in case of MRMs (TransAID services 4 and 5). In that case, occasional ToCs are eliminated within the TA, thereby increasing safety. Services 4 and 5 are quite generic in that way and can be used for any TA. In the same way a geofence could be applied to TAs where driving conditions are very stringent and ToCs are possibly dangerous. A geofence imposed by the TMC would force CAVs to perform ToCs ahead of the TA (with or without the support of service 4 and/or 5).

Relevant use cases and results	Scheduling of ToCs in space and time upstream of no-AD zones was explicitly investigated in the context of UC5.1 "Distribute ToC/MRM by scheduling ToCs", while distribution of ToCs was jointly examined with guidance of MRMs towards safe harbours in UC4.1+5.1 "Distributed safe spots along an urban corridor". Simulation analysis of both UCs showed that the proposed traffic management plans can yield very significant benefits in terms of safety and traffic efficiency. Benefits become more profound in case CAVs attempt to establish increased car-following headways during the ToC-preparation phase. In case geofences are imposed by OEMs instead of the TMC, OEMs could share the reason of the geofence with road authorities / road operators. If possible, one of the TransAID services can be deployed to prevent ToCs altogether. In that sense, use cases from service 1 to 3 are also relevant.
Important stakeholders and their role	**OEMs:** Develop CAVs that can comprehend and enact upon personalised advice and information provided by the TMC side. **Road Authorities:** Indicate geofenced areas and no-AD zones. **Road Operators:** Establish, support, and maintain physical and digital infrastructure necessary for the distribution of ToCs and management of MRMs upstream of no-AD zones. **Service Providers:** Develop services that provide real-time advice to CAVs with respect to ToC execution and guidance to safe spots. **Standardisation Bodies:** Develop communication standards to empower I2V advice with respect to ToC execution and guidance to safe spots.
Stakeholder responses	The idea that there will be areas where AD should not be allowed is somewhat debated. In one survey, 57% foresaw situations where AD should not be allowed. In general, the idea of no-AD zones often pops up during discussions. Frequently, road works zones and tunnels are mentioned as examples.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Research, pilots, and standardisation.
2026-2030	Specifications for no-AD zones. Deployment upstream of selected no-AD zones.
2031-2040	Wide deployment and use. Adaptation of specifications for no-AD zones.
Recurring questions	Are there situations in which AD should not be allowed and if so, which?
Ongoing, relevant and/or future research and innovation activities	The impacts of distributing ToCs and guiding MRMs to safe spots at the borders of geofenced areas were explicitly assessed with the use of microscopic traffic simulation in TransAID. However, TransAID also conducted field trials that assessed the implications of difference strategies

	(i.e., cruising speed while driving in MRM mode) with respect to guidance of MRMs towards safe spots. Future research should consider incorporation of the latter findings in simulation activities, while future field experiments should jointly examine distribution of ToCs and guidance of MRMs to safe spots. Focus should be also placed on the reservation mechanism for safe spots in case of multiple MRMs, and the necessary adaptation of the ToC distribution process given CAV behaviour during ToC (e.g., available lead time offered from the CAV side).

TM5: Real-time lane management *Additional related actions:* *Consider criteria for dedicated lanes*	
General TransAID contribution	TransAID devised a traffic management strategy that separates traffic upstream of motorway merge areas. Road-side infrastructure assigns vehicles to different lanes according to automation level to prevent complex traffic interactions and resulting ToC/MRMs at the merge area. In case CAVs fail to reach the assigned lane, the traffic separation measure is lifted, speed limits are reduced and CAVs are advised to issue proactive take over requests so that MRMs do not take place at the merge area. That way, traffic streams on both motorways will not be impacted.
Relevant use cases and results	Real-time traffic separation was examined in the context of UC3.1 “Prevent ToC/MRM by traffic separation”. Simulation findings suggest that deployment of the latter traffic management strategy is meaningful for approximately equivalent shares of LVs and CAVs in the fleet mix. Additionally, it was identified that provision of lane advice (stay or change) from the TMC side to achieve traffic separation should be distributed in space and time to prevent traffic turbulence occurring from multiple concurrent lane changes (especially when traffic is dense). Finally, cooperative lane changing among CAVs can increase the probability that CAVs reach the designated lane, thus preventing potential MRMs occurring upstream of the merge area and reducing disruption of the traffic separation service.
Important stakeholders and their role	**OEMs:** Develop and manufacture CAVs equipped with communication capabilities that enable cooperative manoeuvring and reception of personalised advice from the TMC side. The CAVs shall ultimately take own decisions based on current situations by following the advices if these do not imply safety risks. **Road Authorities:** Allocate lanes to AVs under certain conditions. **Road Operators:** Deploy and operate physical and digital infrastructure that enables real-time lane management and traffic separation. **Service Providers:** Develop traffic services that enable real-time lane management and traffic separation.

	Standardisation Bodies: Develop communication standards that facilitate the provision of personalised advice to CAVs from TMCs based on their status.
Stakeholder responses	Dedicated lanes for (C)AVs should be considered as an incentive for the introduction of AD to reach long term goals of safety / efficiency. It is best to use dynamic assignment which considers the traffic composition, due to possible reduced capacity (blocking a lane for other traffic). At the beginning and end of dedicated lanes there is increased likelihood of transitions of control which could be prevented or managed via supportive measures. Dedicated lanes for CAVs do not necessarily mean physically separated lanes by the rest of the road infrastructure. Traffic signs were considered rather important for dedicated lanes use cases due to regulatory / legislative reasons.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Research on implementation aspects. Pilots in key motorway areas.
2026-2030	Deployment in motorway areas with higher shares of CAVs in the fleet mix. Adaptation of implementation aspects.
2031-2040	Deployment and use, including adaptation.
Recurring questions	Should motorways have dedicated AV lanes while we are in a transition period? What is proper signage to indicate dedicated lanes for AVs / CAVs / vehicles with certain capabilities?
Ongoing, relevant and/or future research and innovation activities	Optimal lane selection with the support of connected vehicle technology has received significant attention, while dedicated AV lanes is a topic that has not been examined to the same extent. As far as traffic separation is concerned, future research should emphasise on traffic orchestration upstream of the beginning of AV dedicated lanes to prevent control transitions due to intense lane change activity. Similarly, infrastructure assistance beyond the dedicated lanes would ensure smooth merging of traffic streams with different traffic characteristics (automated and manual). Finally, real-life deployment of traffic separation strategies requires the presence of adequate numbers of CAVs in the traffic stream so that they yield significant benefits in terms of traffic efficiency. Thus, deployment of the latter strategies cannot be expected in the short-term.

TM6: Prepare to invest to support the ODD but be very selective	
General TransAID contribution	TransAID developed several traffic management strategies that rely on infrastructure assistance to prevent ToCs/MRMs, thus supporting the ODD of CAVs. The latter measures encompass traffic separation, provision of path information, speed advice, headway advice, lane keep / change advice, and updates regarding traffic regulations. Impact assessment of the latter measures was conducted via simulation analysis, while feasibility assessment was conducted via real world experiments (both on isolated test tracks and public roads).
Relevant use cases and results	The following TransAID use cases pertain to infrastructure-assisted traffic management measures that support the ODD: • UC1.1: Prevent ToC/MRM by providing vehicle path information • UC2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice • UC3.1: Prevent ToC/MRM by traffic separation • UC1.3: Queue spillback at exit ramp • UC2.3: Intersection handling due to incident • UC4.2: Safe spot in lane of blockage & Lane change Assistant Path information provision to CAVs upstream of road works reduced conflict risk, while traffic separation proved to be beneficial for approximately equal shares of LVs and CAVs in the fleet mix and light to moderate traffic demand. Speed advice to on-ramp vehicles, and lane keep / change advice upstream of lane closures (due to incidents or road works) decreased ToC/MRM rate and generated traffic efficiency and safety benefits.
Important stakeholders and their role	**OEMs:** Develop CAVs that can comprehend and enact upon personalised advices and information provided by the TMC side. CAVs shall ultimately take own decisions based on current situations by following the advices if these do not imply safety risks. Contribute to the definition of ODD per AD function. **Road Authorities:** Provide guidelines with respect to ISAD definition for roadway infrastructures. Contribute to the definition of ODD per AD function. **Road Operators:** Maintain and upgrade physical infrastructure to support AD. Deploy and operate digital infrastructure to enable infrastructure-assisted traffic management. **Service Providers:** Develop services that can provide real-time instructions to CAVs (speed, headway, lane keep / change advice, updates on traffic regulations) on a personalised level. **Standardisation Bodies:** Develop communication standards that facilitate the provision of personalised advice to CAVs from TMCs based on their status.

Stakeholder responses	Connectivity was recognised as a key enabler to extend the ODD of AD. It is considered needed to derive clear and unambiguous definitions of ODDs for adoption at both the OEMs and infrastructure side. Defining ODDs is a complex task for the involved stakeholders. ODD requirements differ much between use cases and are going to be period-dependent, but they could also be manufacturer or ISAD level dependent. The ODD will always have limitations for the foreseeable future. ODDs are characterised by very heterogeneous attributes: from parameters that can change very rapidly according to technological evolution (i.e., advance in sensor and computation technologies), to physical infrastructure features that road operators build now to last for the decades to come.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Definition of ODD and ISAD levels. Research and Pilots. Standardisation. Cost-Benefit Analysis per UC. Day 2+ C-ITS services.
2026-2030	Adaptation of definitions for ODD and ISAD. Adaptation of standards. Deployment in key areas.
2031-2040	Deployment and use. continuous adaptation and definitions and standards.
Recurring questions	Which variables (e.g., roadway types, speed range, environmental conditions, sensor capabilities, prevailing traffic law and regulations) must be used to classify an ODD for which a CAV is suited? Should ODD be defined by OEMs internally, without sharing it with anyone, or does the ODD need to be defined commonly, so that the infrastructure can guarantee automation readiness independent of the OEM. Who should decide whether a specific road section is within the ODD of a CAV?
Ongoing, relevant and/or future research and innovation activities	TransAID contributed significantly to the simulative assessment of the impacts of infrastructure-assisted traffic management measures which support and extend the ODD. As more information becomes publicly available with respect to actual CAV behaviour, it is meaningful that TransAID simulation results with respect to use cases 1.1, 1.3, 2.1, 2.3, 3.1, and 4.2 are validated. Field experiments on public are also expected to play a significant role in determining the proposed measures with the highest efficacy. Finally, it is recommended that a cost-benefit analysis is conducted per automation use case to prioritise investment with respect to ODD support.

4.4 Intermediary role and stakeholder collaboration

The roles and responsibilities related to cooperative, connected, and automated mobility (CCAM) touch upon many aspects: vehicle type approval, infrastructure design, traffic laws, ensuring safe automated operation, driver education, liability, road and vehicle maintenance, traffic and incident management, reducing emissions, etc. This section focusses on a set of topics that TransAID encountered during its research and/or were encountered frequently during stakeholder consultation events.

TransAID aims to extend the ODD of AVs or at least manage AVs in case they reach the limit of their ODD through digital infrastructure. Such an approach inherently has an impact on roles and responsibilities of OEMs and road authorities. Primarily, TransAID provides information and advices to vehicles which the vehicles can act on or not. The decision to do so lies with the vehicle and not the infrastructure or road operator. Nevertheless, it is a valid question if the consequences of the vehicles' actions based upon such information or advices should be contributed to the sender or receiver. From TransAID's perspective, the assumption is that vehicles always have their own safeguards from low level obstacle avoidance to higher level tactical decisions (e.g., lane changing, crossing an intersection, etc.). Therefore, the idea is that vehicles always make the determination whether an action is safe based on their own logic (or the driver/(remote) operator, if supervision was required). As a result, the worst-case result of wrong information or advices would be reduced throughput with no damage to vehicles or harm to road users.

However, we found that in some cases an advice can conflict with (current) rules and regulations. There are situations where common-sense dictates that you should temporarily ignore traffic regulations to ensure a safe situation. For example, when the queue on an off-ramp starts to extend to the main carriageway, it is best when the queue uses the emergency lane when available although this conflicts with traffic laws. Another example would be to circumvent an obstacle or incident while using 'off-limits' areas (e.g., bike-lane, bus-lane, etc.).

In those scenarios the vehicle by itself would not determine the required actions as valid or safe. A solution could be to either adapt traffic laws and regulation such that a vehicle can use those rules to mark actions as valid and safe. To prevent ambiguity or uncertainties, laws could dictate that traffic rules can only be broken when this is indicated by information from the roadside. Another, possibly more complex way, would be to define the parameters as part of the regulation so the vehicle can determine (offline) when and in what way deviating from regulation is allowed (although it would not be deviating anymore, since it is part of the regulation).

The reasoning above shows that given a plain point of view of saying the vehicles' systems are responsible for safe AD, additional mechanics, and/or regulations are required to overcome edge cases. Those mechanics and/or regulations mean involvement of road authorities and/or legislators. Hence, the services created by TransAID require intensive cooperation between OEMs and other stakeholders and in many cases, they share some responsibility.

As explained in section 2.6 we put emphasis on a strong collaboration between OEMs and (N)RAs, especially considering managing TAs. TransAID proposes an intermediary service provider, acting as a trusted (and possibly mandated) third party. Considering this future intermediary role, there are various topics to which TransAID contributed, i.e.:

- IR1: Use digital technologies to dynamically identify yet emerging new frontiers / unknown unknowns
- IR2: Fleet supervision centres
- IR3: Supply information on ODD boundaries
- IR4: Harmonised management of incident sites / Harmonised management of road works sites

  - *Harmonised marking of incident sites / Harmonised marking of road works sites*
  - *Provision of incident and event management related data to traffic managers and service providers*
- IR5: Standardisation concerning the marking and management of incident sites
- IR6: Provision of ODD management
  - *Consider role of road authorities in ODD management*
- IR7: Integration of operations management centre and traffic management centre
  - *Consider role of road authorities in ODD management*
- IR8: Accountability in case of mistakes or conflicting interpretation
  - *Product liability issues for digital infrastructure*

IR1: Use digital technologies to dynamically identify yet emerging new frontiers / unknown unknowns	
General TransAID contribution	TransAID primarily contributed on the level of simulation assessments, by incorporating what-if scenarios that are currently non-existing. These scenarios highlight various conflict situations that may arise when mixing human-driven traffic (i.e., both legacy vehicles as well as vehicles supported with some ADAS features) with traffic that is automated to a certain degree (i.e., Level 3 and higher). Our simulations exposed current weak points in traffic management, which on the longer term will need to provide suitable approaches for dealing with the different kinds of vehicles (and their behaviours). As such the concept of TAs was thoroughly studied and introduced. We now have much more insight into potential problems with mixed traffic in TAs and possible solutions.
Relevant use cases and results	All TransAID use cases showed potential issues with mixed traffic in TAs. What situations exactly will result in TAs heavily depends on the exact implementation of the HMI, AD functions, and the level of support of infrastructure (ISAD level). TransAID's use cases show likely scenarios in which some measures are needed to mitigate effects of ToCs in TAs in mixed traffic conditions.
Important stakeholders and their role	**OEMs:** Provide the intermediary Service Provider with the ODD of their vehicles. **Road Authorities / Road Operators:** These need to cooperate and align, together with the OEMs, as to what behaviour can be expected and how to optimally design traffic management goals and schemes such that (ideally) unexpected situations do not arise or are at least minimised and dealt with a priori to a strong degree. **Service Providers:** Support the Road Authorities and the OEMs as an intermediary with the development of ODD and ISAD concepts.
Stakeholder responses	TransAID focusses on a very specific problem (managing mixed traffic in TAs) and we found that little is known about that problem, which confirms the need and timeliness of TransAID. During the beginning of the project a workshop was held with stakeholders to identify which situations likely result in TAs. The focus was on

	identifying relevant aspects to be considered for creation of use cases and scenarios at TAs such as: the cause of disengagements, the ToC process, expected levels of AD, relevant actors, etc. The short conclusion of that effort was that stakeholders and experts were at the time unable to provide answers with sufficient details. We did get better answers on the separate aspects, but those vary a lot depending on who you ask. Regarding the concept of the ODD, one of the main barriers is the exact definition: how to specify the capabilities of an AV? In addition, sharing such information is in conflict with OEM's IPR.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Preliminary research continues primarily regarding ODD and ISAD levels.
2026-2030	Results from the EU's Safety-Related Traffic Information (SRTI) Directive are shared with research institutes and fed back to the road authorities, OEMs and service providers. Useable concepts of ODD and ISAD (or alternative concepts) which can be used to identify TAs.
2031-2040	Fully integrated data streams that flow as V2V, V2I, and vice versa, as well as road authorities that have access to these. TAs can be identified through data sharing on a strategic and operational level.
Recurring questions	How to define the ODD of AVs? How can ODDs be shared? What situations will result in TAs and how will (C)AVs respond in those areas (MRM/ToC behaviour)? What digital information from infrastructure will be available? To what extent will OEMs accept a dependency on external information for AD?
Ongoing, relevant and/or future research and innovation activities	Studies for DG MOVE (cf. Study on the Effects of Automation on Road User Behaviour and Performance) as well as CEDR 2020 calls, topic C dealing with Traffic Management.

IR2: Fleet supervision centres *Original action title: Road operator fleet supervision centres*	
General TransAID contribution	TransAID explored active collaboration between OEMs and (N)RAs, especially in light of managing TAs. As such, TransAID's proposal of an intermediary service provider that acts as a trusted third party is of direct relevance to these supervision centres. It can be expected that such supervision centres will be a valuable source of disengagements (ToC)

	which can help in the identification of TAs. In addition, the identification of TAs can help set up procedures at these supervision centres to proactively manage vehicles approaching TAs.
Relevant use cases and results	All TransAID use cases are relevant since any TA will require attention from a supervision centre. In addition, if a disengagement (ToC) requires actions from the centre, TransAID's service 5 (distributing ToC/MRM by scheduling ToCs) is of specific interest. In other cases, supervision centres might have their own measures to mitigate TAs (i.e., provide additional information, instructions to the vehicle and/or remote control options).
Important stakeholders and their role	**OEMs:** Provide required information to the fleet supervisors at the moment contracts are drawn up and collaborations are started. The communication capabilities, the provided vehicles' ODDs, etc., are all relevant information that needs to be known by the fleet supervisors. **Road Operators:** Support identifying TAs. **Service Providers:** Identify TAs and provide fleet supervision centres with the needed information. Collect disengagements from fleet supervision centres. **Standardisation Bodies:** Develop standards to facilitate the exchange of TA information.
Stakeholder responses	No explicit statements were given by fleet supervisors / owners, nor by OEMs. Road operators and service providers were open to the idea, especially since it allows them to better focus on their respective core tasks, e.g., policy definitions.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Research and limited pilots. Explore the role of supervision centres in identifying and managing TAs.
2026-2030	Introduction of Service Providers that act as intermediaries between fleet supervision centres and Road Authorities / Road Operators.
2031-2040	Strong and continued interactions between all key stakeholders, including the ends of the spectrum where road authorities and OEMs reside.
Recurring questions	What are the capabilities of fleet supervision centres to support AD? What is the legal position of fleet supervision centres? What does the liability and/or responsibility of supervision centres look like when they actively influence the behaviour of AVs? To what degree will OEMs have to share information, and to what degree are they liable?
Ongoing, relevant and/or future	There are several initiatives linked to fleet supervision centres, primarily in the domain of public transport (shared AVs) and transportation (moving goods).

research and innovation activities	

IR3: Supply information on ODD boundaries *Original action title: Supply information on ODD termination risks*	
General TransAID contribution	When AVs approach the boundaries of their ODDs, take over requests may be issued to their drivers/(remote) operator, possibly resulting in MRMs. The goal of TransAID's traffic management is to prevent / postpone this to the highest extent possible. As such, information on when these boundaries can be encountered is necessary to be relayed to the traffic management centres (be it road operators, fleet providers, or an intermediary service).
Relevant use cases and results	All TransAID use cases are relevant since any TA is an ODD termination risk. This is true for foreseeable TAs as well as incidental TAs.
Important stakeholders and their role	**OEMs:** Contribute to the ODD and ISAD specification. Share ODD limitations. **Road Authorities / Road Operators:** Contribute to the ODD specification. These stakeholders also need to supply information back to the OEMs (i.e., ISAD information). The latter is especially important in case there are dynamic changes to the driving environment that are externally given, e.g., changing speed limits, (unplanned) road works. **Service Providers:** Parties such as map makers play a crucial role here, in facilitating the OEMs on the one hand to provide them with up-to-date information on what the infrastructural elements are, and on the other hand with any changes to the maps that are of a more dynamic nature. In addition, when acting as a trusted third party, service providers can facilitate anonymous disengagement reports to both OEMs (sharing) and road authorities / road operators.
Stakeholder responses	Most stakeholders (of various sorts) agree that such information needs to be made available by OEMs. The latter however do not always share that concern, and place more stringent conditions on when, where, and why specific information should be shared.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Further development of the ODD and ISAD concepts.
2026-2030	The provision of road infrastructure-related information from road authorities to all other entities (an example is the dissemination of the information through national databases via a standardised DATEX II feed). Transition towards a distribution of OEM's ODD-related information to road authorities and service providers.

	Develop legal frameworks around the requirements of sharing ODD and ISAD information.
2031-2040	Adherence of OEMs and road authorities / road operators to the legal requirements of sharing ODD / ISAD information (for major roads).
Recurring questions	What exact ODD / ISAD information needs to be provided and what will its purpose be? How is an ODD boundary influencing the performance of traffic management systems?
Ongoing, relevant and/or future research and innovation activities	Studies for DG MOVE (cf. Study on the Effects of Automation on Road User Behaviour and Performance) as well as CEDR 2020 calls, topic C dealing with Traffic Management. In addition, there are several other initiatives to develop the ODD and ISAD concepts as they are, at the time of writing, 'hot topics' in the field of CCAM. The EU H2020 INFRAMIX project. For sharing ODDs, possible formats are currently discussed e.g., at ASAM (OpenODD) and ISO.

IR4: Harmonised management of incident sites / Harmonised management of road works sites *Additional related actions:* *Harmonised marking of incident sites / Harmonised marking of road works sites* *Provision of incident and event management related data to traffic managers and service providers*	
General TransAID contribution	TransAID provided contributions to this aspect on two levels. First, it strives towards dynamically detecting transition zones, of which incident sites are a prime example. Secondly, the proposed intermediary role provides a means to efficiently deal with changing situations on the road, alerting and managing the various involved parties (i.e., OEMs and fleet providers on the one hand, and road authorities on the other hand). The same line of reasoning holds true in case of event management-related data, which can be seen as a specific instance of incident information.
Relevant use cases and results	Of direct relevance here are use cases that involve road works or incidents such as UC1.1 (Provide path around road works via bus lane) but then considered from a broad perspective (including the detection of incidents), UC2.3 (Intersection handling due to incident) which is directly applicable, and indirectly UC4.2 (Manage MRM by guidance to safe spot (& lane change assistant)) and UC4.1 + 5.1 (Distributed safe spots along an urban corridor).
Important stakeholders and their role	**OEMs:** Recipients of the information (both of the raw information of incident locations, typology, and duration) as wells as information formulated in the form of advice in light of external traffic management

	decisions. Note that they also serve a purpose, in light of sharing information, in detecting and reporting incidents to the infrastructure (manager). **Road Authorities and Road Operators:** Detect and provide the incidents and related location and typology information to either a third party, or to fleet operators / OEMs directly. In addition, they would also receive information from the OEMs, in case this is shared (e.g., by having it enforced via the EU's Safety-Related Traffic Information (SRTI) Directive). **Service Providers:** Act as a third party in order to provide alignment and harmonisation of information across the other stakeholders.
Stakeholder responses	There is a consensus among road authorities and service providers that externalising the coordination and harmonisation of this information could be a positive aspect for traffic management. In additions, OEMs also welcome this kind of information, as it allows them to make their vehicles more adaptable to certain situations.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Setting up the framework in which such harmonisation and coordination of information between all involved stakeholders can occur.
2026-2030	Institutionalising such information by means of enabling legislation to lend a mandate to certain service providers in light of traffic management services.
2031-2040	Complete integration of incident-related information across the entire chain of stakeholders.
Recurring questions	What information (i.e., attributes) needs to be shared? What is the required quality of the information, and who is responsible for monitoring the quality? Who is liable in case of incorrect information, and where along the chain of stakeholders does the liability lie?
Ongoing, relevant and/or future research and innovation activities	The Talking Traffic C-ITS programme in the Netherlands. The Mobilidata C-ITS programme in Flanders, Belgium. The EU CEF SOCRATES$^{2.0}$ project.

IR5: Standardisation concerning the marking and management of incident sites	
General TransAID contribution	Regarding the management of incident sites, the TransAID services provide generic solutions to various situations. In that way, TransAID standardised the management of TAs.

	In addition, the implementation of the services also uses common mechanisms like cooperative perception and cooperative manoeuvring. Future steps could include investigations into which service(s) are best applied to which situation. Furthermore, TransAID contributed to this aspect by means of providing extensions to V2X data containers that supply the required information to the various involved parties. Whereas the information exchange regarding the locations of incidents and how this is to be transmitted between vehicles themselves and to/from the infrastructure, there is still a need to define how traffic management-related information can be standardised. The latter occurs typically on a higher level and was out of scope of the TransAID project.
Relevant use cases and results	Of direct relevance here are use cases that involve road works or incidents such as UC1.1 (Provide path around road works via bus lane) but then considered from a broad perspective (including the detection of incidents), UC2.3 (Intersection handling due to incident) which is directly applicable, and indirectly UC4.2 (Manage MRM by guidance to safe spot (& lane change assistant)) and UC4.1 + 5.1 (Distributed safe spots along an urban corridor).
Important stakeholders and their role	**OEMs / Road Authorities / Road Operators:** all these stakeholders need to partake in the Standardisation Bodies in order to reflect their individual requirements and capabilities, so as to reach a consensus that benefits everybody involved. Failure to do so would provide hindrance to achieving harmonised traffic management. **Standardisation Bodies:** Draft agreements for cooperation and standards to exchange marking and management information regarding incident sites.
Stakeholder responses	These kinds of aspects were not directly discussed with participating stakeholders. There was however a consensus that standardisation bodies such as ETSI, SAE, and IEEE should be involved.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Gathering consensus on all related information regarding what aspects are relevant and need to be included in the extensions of the default data containers for, e.g., MAPEM and DENM messages in the context of V2X (or other vehicular communications) and DATEX II between stakeholders.
2026-2030	Agreement on final drafting of the standardisation requirements and generate awareness among stakeholders of the importance of participation.
2031-2040	Updates to the standardised message containers, in a swift manner that does not impede any party (i.e., OEMs can continue their development paths without having to drastically change directions because of new requirements).
Recurring questions	Which message container extensions are required and go beyond the current SRTI-related information?

	What are the requirements on data accuracy and quality, as well as timeliness for the exchanged messages?
Ongoing, relevant and/or future research and innovation activities	There has been considerable progress already on the marking (encoding) of incident sites (e.g., DENM, DATEX II). Limited adaptations are expected to also include TA specific information. The exchange of traffic measures / plans needs considerably more research and standardisation. Examples of current initiatives are MaTmEx and EU CEF SOCRATES[2.0].

IR6: Provision of ODD management *Additional related actions:* *Consider role of road authorities in ODD management*	
General TransAID contribution	(Dynamic) ODD management is required when, i.e., high traffic intensities or certain weather conditions fall outside the ODDs. Under these conditions, TransAID investigated to what degree it can provide information to the vehicles that would either augment their ODD, or understand when they are at risk of reaching their ODD boundaries and hence provide a performant and safe continuation of the trips, i.e., executing dynamic traffic management. Another important aspect here is the required digitalisation of traffic rules and regulations in a harmonised and secure manner. In addition, the current trend is that ODD management goes hand in hand with the ISAD levels concept. For example, when ISAD levels change due to circumstances, AD might no longer be possible due to the lack of support from the infrastructure.
Relevant use cases and results	All TransAID use cases showed potential ODD boundaries and thus the need of ODD management. What situations exactly will be outside the ODD depends heavily on the exact implementation of the AD functions and the level of support of infrastructure (ISAD level).
Important stakeholders and their role	**OEMs:** Recipients and distributors of their vehicles' ODD-related data. It is of special importance to incorporate the dynamic nature of the vehicles' surroundings. Discuss supporting measures (and their requirements) to manage vehicles reaching their ODD limit. **Road Authorities / Road Operators:** Provide the first step in detecting dynamic changes in the traffic system (ISAD level). This can be done by providing raw data to a service provider (i.e., traffic manager) that can then use this information to augment the vehicles' ODD awareness. Discuss supporting measures (and their requirements) to manage vehicles reaching their ODD limit. **Service Providers:** Match the (dynamic) ODD to the ISAD levels, detect incidents, and monitor the infrastructure in general to identify and disseminate TAs, and thus possible ODD boundaries. Discuss supporting

	measures (and their requirements) to manage vehicles reaching their ODD limit. **Standardisation Bodies:** Develop standardisation around the ODD and ISAD concepts.
Stakeholder responses	Some responses (irrespective of the type of stakeholder) were mixed, in that some believe control of a vehicle (in case of a conflict between the vehicle and the traffic management system) should remain with the vehicle, while others (a slight majority) are of the opinion that the vehicles should follow the instructions of the traffic management system. This has direct consequences for who is to control the ODD information flow, and how to respond to it.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Further development of the ODD and ISAD concepts. Discuss supporting measures (and their requirements) to manage vehicles reaching their ODD limit.
2026-2030	The provision of road infrastructure-related information from road authorities to all other entities (an example is the dissemination of the information through national databases via a standardised DATEX II feed). Transition towards a distribution of OEM's ODD-related information to road authorities and service providers. Develop legal frameworks around the requirements of sharing ODD and ISAD information. Discuss supporting measures (and their requirements) to manage vehicles reaching their ODD limit.
2031-2040	Adherence of OEMs and road authorities / road operators to the legal requirements of sharing ODD / ISAD information (for major roads). Implementation of supporting measures (and their requirements) to manage vehicles reaching their ODD limit.
Recurring questions	What kind of minimal ODD-information is required (both to be sent and received by all involved parties)? Who is liable in case of faulty information (e.g., incorrect or inaccurate data sent from the infrastructure to the vehicle)?
Ongoing, relevant and/or future research and innovation activities	Studies for DG MOVE (cf. Study on the Effects of Automation on Road User Behaviour and Performance) as well as CEDR 2020 calls, topic C dealing with Traffic Management. In addition, there are several other initiatives to develop the ODD and ISAD concepts as they are, at the time of writing, 'hot topics' in the field of CCAM. The EU H2020 INFRAMIX project.

	For sharing ODDs, possible formats are currently discussed e.g., at ASAM (OpenODD) and ISO.

IR7: Integration of operations management centre and traffic management centre *Additional related actions:* *Consider role of road authorities in ODD management*	
General TransAID contribution	This is probably the most directly applicable aspect for TransAID in light of further exploitation as a third-party intermediary service provider. The traffic management part is driven by policy goals, which are then translated into set points, and combined with the current and future estimated state of the network lead to operational advice given to the fleet managers / OEMs' individual vehicles.
Relevant use cases and results	All uses cases are indirectly relevant, in that the traffic management scenarios all resemble a proxy between the individual vehicles on the roads and the road authority that resides at the upstream end of the RSUs operational in the field.
Important stakeholders and their role	**OEMs / Road Authorities / Road Operators:** These stakeholders sit at opposite sides of the spectrum here, each having their own goals. The former, including fleet operators, act on a more individualistic basis, whereas the latter try to balance the scales to take the system optimum into account (i.e., network optimum). **Service Providers:** Can act as a trusted third party and intermediary between road authorities / road operators and OEMs. They can develop specific knowledge regarding ODD limitations, infrastructure support and TAs in particular. Because of centralised knowledge and the trusted aspect, they could receive the needed trust from all involved parties. Also, it enables them to develop the needed competency to integrate the information flows and act upon them.
Stakeholder responses	In a majority of the cases the roles of infrastructure managers remain very relevant to provide support at TAs. However, there are some specifics involved that may not be as straightforward. For example, in one case a majority of the responses pointed towards more autonomy of the vehicles, having the road authorities *not* providing dedicated infrastructure for AD.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	The timeline here follows more or less the planned exploitation of the TransAID intermediary service provision. This entails first more collection of information and use cases, based on the efforts in other projects.
2026-2030	A more concrete exploitation, field trialled and operationally deployed in certain pilot cities.

2031-2040	Different types of traffic management service provisioning based on a variety of geographic scopes.
Recurring questions	Who determines what data is required by and for whom? Who has the liability regarding information provisioning and traffic management advice? To what extent will AVs act upon information from external sources?
Ongoing, relevant and/or future research and innovation activities	nuMIDAS Horizon 2020 project[7]. Studies for DG MOVE (cf. Study on the Effects of Automation on Road User Behaviour and Performance) as well as CEDR 2020 calls, topic C dealing with Traffic Management. In addition, there are several other initiatives to develop the ODD and ISAD concepts as they are, at the time of writing, 'hot topics' in the field of CCAM. For sharing ODDs, possible formats are currently discussed, e.g., at ASAM (OpenODD) and ISO.

IR8: Accountability in case of mistakes or conflicting interpretation *Additional related actions:* *Product liability issues for digital infrastructure*	
General TransAID contribution	Although accountability was not specifically studied in TransAID, we did touch upon the subject in discussions. The TransAID services send advices, not commands, to vehicles to mitigate impacts of TAs. Therefore, it is up to the vehicle to follow the advice or ignore it. We assume the responsibility for safe vehicle behaviour lies with the vehicle automation (or if the human should supervise, the driver/(remote) operator). Thus, in case of accidents when automation was enabled, responsibility is linked to the vehicle in the same way as if a human were driving that vehicle (e.g., when an AV is rear-ended, the following car / driver is responsible). Regarding 'mistakes', which could be defined as reduced throughput or a vehicle being guided in the wrong direction (regarding its route) the responsibility lies with the entity giving the advice. An edge case would be when the advices result in less safe circumstances. Such advices should always consider the ODD limitations of AVs. Nevertheless, it might be possible, for example, that as a result of the advice, traffic flows emerge with reduced headways and thus very short time to collisions. When a vehicle in automated mode creates an accident, either its automation (i.e., OEM) or the driver/(remote) operator (in case of supervision) is responsible. The same is true for non-automated vehicles:

[7] www.numidas.eu

	the driver is responsible in case of no mechanical / machine failure. However, if this happens frequently, we believe the road authority should take action to make the advices safer.
Relevant use cases and results	Since information or advices are provided in all use cases, all are relevant regarding accountability. However, use cases 1.1, 1.3, 2.3 and 4.2 are more relevant than the others because they include advices to use the road in a different way than intended / allowed. UC1.1 reroutes traffic via a bus lane around road works. As part of the road works measures, the bus lane can be used by all vehicles. It is the responsibility of the road authority or contractor to inform the vehicles about this changed topology. Consequently, they are in part responsible for the continuation of traffic. UC1.3 extends an exit onto the emergency lane in case of spillback. Again, the intended use of the road is changed, and vehicles can move onto the emergency lane when taking the exit. This advice conflicts with rules known by the CAVs, thus road authorities should bear some responsibility if the CAVs are to trust that information. In UC2.3 there is an accident just before an intersection, blocking the lane use for the right turn. Intersection topology and signal timings are adjusted to facilitate a right turn from the lane next to it. The same aspects apply as in UC1.3 described above. Finally, UC4.2 introduces a safe haven, which is an area where an (C)AV performing an MRM can safely stop without disrupting the traffic flow. This area is usually not available for emergency stops and hence there is a conflict with the (“normal”) information available to an (C)AV. The same aspects apply as in UC1.3 described above.
Important stakeholders and their role	**OEMs:** Responsible for safe driving and avoiding collisions. Interpreting advices from Road Operators. Engage with road authorities and road operators to create a common understanding of services. **Road Authorities:** Establish information and advices to vehicles. Engage with OEMs to create a common understanding of services. **Road Operators:** Send information and advices to vehicles and make sure traffic conditions remain safe regarding the effect of the information / advices. **Service Providers:** Can act as a trusted third party and intermediary between road authorities / road operators and OEMs. They can develop specific knowledge regarding ODD limitations, infrastructure support and TAs in particular. Because of centralised knowledge and the trusted aspect, they could receive the needed trust from all involved parties. Also, it enables them to develop the needed competency to integrate the information flows and provide the TransAID / TM services. **Standardisation Bodies:** Develop liability frameworks.
Stakeholder responses	The question of accountability is not an easy question and the need of new governing / regulatory framework is recognised with no exception. It is also

	recognised that cross-country differences further complicate such frameworks because of differences in the legal landscape. Something that was also observed when TransAID visited the US for a twinning event with the U.S. CAMP. Financial consequences because of liability (through lawsuits) can be quite substantial, which is one of the reasons U.S. OEMs are very hesitant when considering V2X infrastructure support for AD. On the other hand, during events in Europe and Japan the infrastructure support (and hence communications) is welcomed by the majority of stakeholders. Additionally, it was often acknowledged that there is the need to adapt traffic rules for automation, for example, to differentiate speed / relevance areas for different categories of vehicles. In addition, infrastructure must be authorised by road authorities to provide advices to vehicles (that possibly break traffic rules) in a fast and dynamic way or be mandated for recurrent situations. This was an important finding and points again to the need of new regulation.
Timeline	*Below recommended steps are provided given different time horizons.*
2021-2025	Pilots to investigate collaboration between infrastructure and OEMs. Cooperation between OEMs and road authorities to harmonise the need and understanding of information provided to vehicles (ODD & ISAD). Start working on governing / regulatory frameworks covering liability and accountability.
2026-2030	A more concrete exploitation, field trialled and operationally deployed in certain pilot cities. Continue working on governing / regulatory frameworks covering liability and accountability.
2031-2040	Continue working on and updating governing / regulatory frameworks covering liability and accountability.
Recurring questions	The whole aspect of accountability, who is responsible for what, is in general a recurring question. A more specific related question is: to what extent will OEMs allow their cars to be dependent on information from external sources?
Ongoing, relevant and/or future research and innovation activities	The EU FP7 AdaptIVe project has looked into legal questions resulting from automation. The project lex2vehicle - bring traffic laws to the end user – is researching how traffic laws can be followed by AVs (https://lex2vehicle.com/). German project PAcT (Proving Accountability in Traffic): Technical University of Munich is investigating how laws can be formalised to be approved by software automatically.

5 Conclusion

TransAID has successfully shown the possible issues that arise in TAs due to ToCs in a condensed time and space, and developed and tested several measures to address those issues as reported in section 2 and TransAID deliverable D8.2.

Here, we have taken those results and merged them with feedback from stakeholders (i.e., OEMs, road authorities, road operators, service providers, and standardisation bodies), as reported in TransAID deliverable D8.1, to provide the field of CCAM with recommendations for future actions for the coming 5, 10 and 20 years. As a basis, summaries of other roadmap, guidelines and action plans are provided in section 3 from which we used those of EU EIP and MANTRA to expand upon with our own guidelines and roadmaps in section 4.

The views and questions from stakeholders provide valuable context since these are exciting times for aspects regarding AD and its relation with road infrastructure and traffic management. As we have experienced, there are several discussions and uncertainties which will not disappear soon or new uncertainties will arise. The stakeholder responses and questions in the action tables of section 4 are therefore useful to consider when planning future activities.

We are confident the work provided here brings us a step closer to a future where road users can enjoy the benefits of AD supported by infrastructure due to the fact we addressed Transition Areas for Infrastructure-Assisted Driving (TransAID).

6 References

For convenience and readability, the references are split into two sections. The first lists the relevant TransAID deliverables and where to find them. The second lists all external references.

6.1 TransAID documents

Below in Table 2, an overview is presented of all the deliverables of the TransAID project referenced in this deliverable. All the documents can be found on the website, except for D7.1 which is confidential.

https://www.transaid.eu/deliverables/

Table 2: Overview of TransAID deliverables

WP No.	Del. No.	Title	Release date
2	D2.1	Use cases and safety and efficiency metrics for smooth and safe traffic flow in Transition Areas	Mar-2018
2	D2.2	Scenario definitions and modelling requirements	May-2019
3	D3.1	Modelling, simulation and assessment of vehicle automations and automated vehicles' driver behaviour in mixed traffic	Sep-2019
3	D3.2	Cooperative manoeuvring in the presence of hierarchical traffic management	Feb-2020
4	D4.1	Overview of existing and enhanced traffic management procedures	Sep-2019
4	D4.2	Preliminary simulation and assessment of enhanced traffic management measures	Jan-2021
4	D4.3	Suitability and effectiveness study of traffic management strategies	May-2020
5	D5.1	Definition of V2X message sets	Aug-2019
5	D5.2	V2X-based cooperative sensing and driving in Transition Areas	Mar-2020
5	D5.3	Protocols for reliable V2X message exchange	Mar-2020
5	D5.4	Signalling for informing conventional vehicles	May-2020
6	D6.1	An integrated platform for the simulation and the assessment of traffic management procedures in Transition Areas	Oct-2018
6	D6.2	Assessment of traffic management procedures in Transition Areas	Feb-2021
7	D7.1	System architecture for real world vehicles and road side	Jun-2019
7	D7.2	System prototype demonstration	Feb 2021
8	D8.1	Stakeholder consultation report	Aug-2020
8	D8.2	Meta-analysis of the results	Dec-2020

6.2 External references

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Gold, C., Naujoks, F., Radlmayr, J., Bellem, H., & Jarosch, O. (2017). Testing Scenarios for Human Factors Research in Level 3 Automated Vehicles. In International Conference on Applied Human Factors and Ergonomics (pp. 551–559). Springer.

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Appendix A: Overview of TransAID use cases

This appendix gives a basic overview of the use cases studied by TransAID. It provides descriptions for each use case situation. Detailed descriptions, timelines of actions, sequence diagrams, simulation (baseline) results with and without communication, etc. can be found in TransAID deliverables D2.1, D2.2, D3.1, D4.2 and D6.2. In addition, TransAID deliverable D8.2 provides a comprehensive summary of the results per use case. In the figures below, CAVs are coloured blue.

Use case 1.1 - Provide path around road works via bus lane

In this scenario, there are road works on a three-lane urban road. Due to the resulting road closure, vehicles are by law temporarily allowed to use the bus lane around the work zone (see Figure 5). Such changes in road usage may lead to C(A)Vs not detecting the situation properly, resulting in the need to take a ToC/MRM action. To keep traffic flowing smoothly, the TMC can assist these C(A)Vs in planning their path around the obstacle. This is done by providing the path information, allowing the use of the bus lane by the respective C(A)Vs at the adequate road section. A ToC/MRM action due to incomplete information regarding a possible route continuation can therefore be avoided for many C(A)Vs. Some may still perform a ToC due to different reasons and concerns, such as not receiving or unable to process the path information, or if the driver wants to take over. LVs will still receive the path information via conventional signalling.

Moreover, the TMC advises C(A)Vs to operate with increased headways close to the merging section if vehicles are present on adjacent lanes. After passing the merge area, vehicles' gaps are no longer under control of the TMC.

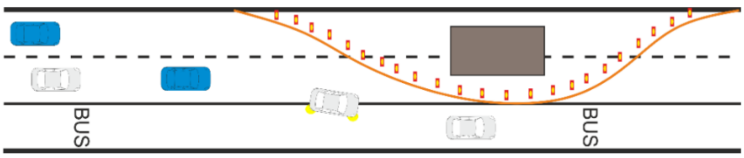

Figure 5: scenario layout of use case 1.1

Use case 1.3 - Queue spillback at exit ramp

Figure 6 depicts a CAV (blue) and LVs (light-coloured) approach an exit on a motorway. There is a queue on the exit lane that spills back onto the motorway. We consider a queue to spill back on the motorway as soon as there is not enough space on the exit lane to decelerate comfortably (drivers will start decelerating upstream of the exit lane). Vehicles are not allowed to queue on the emergency lane but queuing on right-most lane of the motorway will cause (a) a safety risk due to the large speed differences between the queuing vehicles and the regular motorway traffic, and (b) a capacity drop for all traffic (including vehicles that do not wish to use the exit). In the baseline of this scenario (see also TransAID deliverable D3.1) vehicles queue on the main road and the speed limit remains unchanged (drivers/AVs must decide on their own to slow down when they notice the queue).

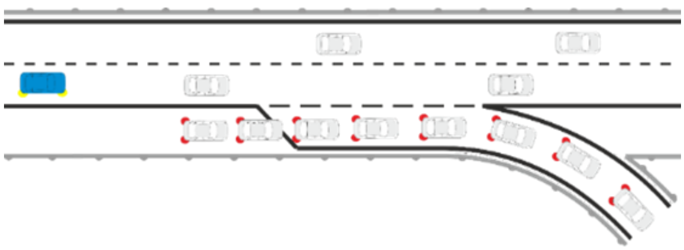

Figure 6: scenario layout of use case 1.3

Use case 2.1 - Prevent ToC/MRM by providing speed, headway, and/or lane advice

CAVs, AVs, CVs, and LVs drive along a motorway merge segment or enter the mainline motorway lanes through an on-ramp. The RSI monitors traffic operations along the motorway merge segment and detects the available gaps on the right-most mainline lane to estimate speed and lane advice for merging CAVs and CVs coming from the on-ramp. The scenario assumes that CVs continuously update their speed and position information to the RSI (in a near-real-time fashion), while CAVs also update their current lane and share perception information of other vehicles around them. In addition, the RSI also fuses this information with measurements obtained via available road-side sensors. The speeds and locations of AVs and LVs can be estimated based on the information gathered via the latter sensors and the location (and available sensing information) of the other vehicles (being CAVs or CVs). The core of this scenario is finding gaps in the motorway's right-most lane (that is not part of the on-ramp). C(A)Vs are guided to these gaps with speed advice, because even with very low traffic volume they could arrive right next to other vehicles in the merging area by chance in the absence of guidance. If the available gaps are not large enough to allow the safe and smooth merging of on-ramp vehicles, speed and lane advices are also provided to the CAVs and CVs driving on the main road, thereby creating the necessary gaps in traffic to facilitate the smooth merging of on-ramp vehicles.

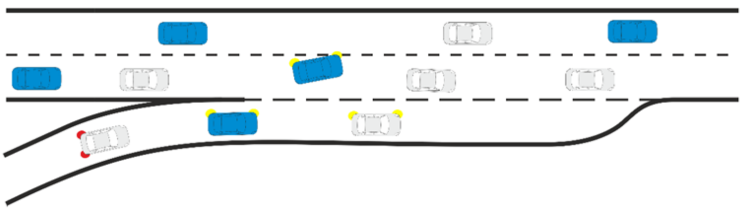

Figure 7: scenario layout of use case 2.1

Use case 2.3 - Intersection handling due to incident

CAVs, AVs, CVs, and LVs are driving towards a signalised T-intersection (see Figure 8). Each arm of the intersection consists of two entry lanes and one exit lane. An incident occurs just before the stop line of the right turning traffic lane on the west approach (approach C, lane 5). The incident is blocking lane 5 approximately 35 meters before the stop line and therefore vehicles driving on this lane will need to use the through traffic lane (approach C, lane 6) to drive around the incident. The RSI will monitor traffic operations along the signalised T-intersection. After the RSI detects an incident, traffic managers will firstly try to create a safe situation on the incident location. This is done by broadcasting the incident information to approaching vehicles, close the lane on the incident location, and set a temporary speed limit around the incident zone. To be able to guide automated vehicles alongside the incident and to make the right turn possible again for all the traffic lanes, usage of lane 5 and 6 are altered and the timing plan (TLC) is changed to make right turns from lane 6 possible. This information is then relayed to the approaching vehicles.

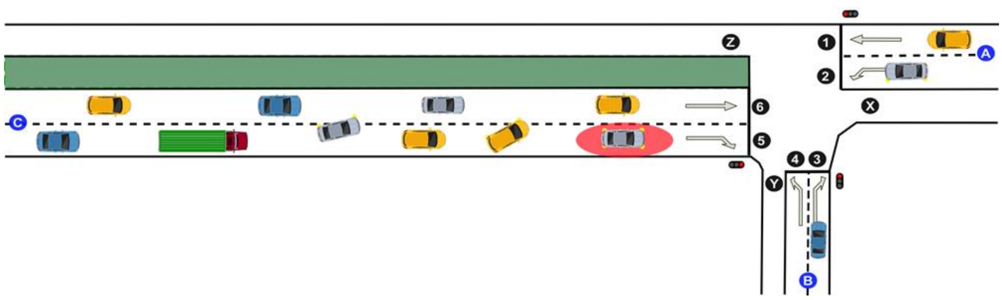

Figure 8: scenario layout of use case 2.3

Use case 3.1 - Prevent ToC/MRM by traffic separation

The interaction between automated and non-automated vehicles, especially at highway merge areas (see Figure 9), can create dangerous situations due to the unpredictable behaviour of human drivers. This can result in that CAVs need to perform a ToC or MRM. However, CAVs' drivers who are allowed to be involved in secondary driving tasks can find it hard to perform a ToC. To avoid these situations, TransAID's service 3 defines a traffic separation policy that places automated and manually driven vehicles at different lanes to minimise the lateral vehicle interactions at the merge area and thus reduce the number of ToCs.

The TMC monitors the approaching vehicles to determine which vehicles need to perform a lane change following the traffic separation policy. The TMC sends lane change advices to the identified vehicles that need to perform the lane change once they close in on the merge area. The lane change advice includes the triggering point of ToC which defines the position where the CAV should trigger a ToC if the advice has not been followed. In this scenario, the triggering point of ToC is defined as the start position of the TA. If a CAV reaches the TA without performing the necessary lane change, a ToC will be initiated, and eventually an MRM if the ToC fails. This is done to assure that the traffic separation policy is fulfilled by all vehicles. Thus, complex interactions in the merge area between manually and AD vehicles are avoided reducing the risk of ToCs and/or MRMs in the merge area. Note that, an MRM in the merge area will disrupt both traffic streams. Hence, it is preferable to perform the ToCs/MRMs upstream of the merge zone to minimise the disruption of the traffic streams.

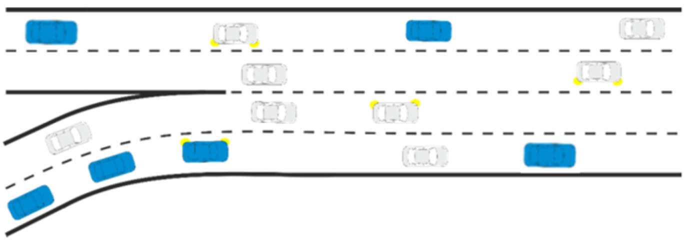

Figure 9: scenario layout of use case 3.1

Use case 4.2 - Manage MRM by guidance to safe spot (& lane change assistant)

A construction site is covering one lane of a two-lane road (urban or motorway) (see Figure 10). The RSI continuously collects information about the construction area and the vicinity of it and provides it to the approaching CAVs. Some CAVs are not able to pass the construction site without human intervention due to system limitations. Therefore, system-initiated ToCs take place somewhere upstream of the construction site. If any ToCs are unsuccessful, the respective CAVs perform MRMs. Without additional measures, the CAV would simply brake and stop on the lane it is driving. Thus, if it stops on the right free lane it will majorly disrupt the traffic flow, while if it stops further upstream of the work zone on the left lane it will essentially create a second lane drop bottleneck. To avoid the latter situations, the RSI which is monitoring the area just in front of the construction site, offers pre-determined spaces as safe stops to the vehicle, if they are not occupied by surrounding traffic. The CAV uses the safe spot location information to come to a safe stop in case of an MRM.

In addition to the generic refinement of the vehicle models introduced in the project's second iteration, this use case was expanded to support CAVs with lane changes trough cooperative manoeuvring.

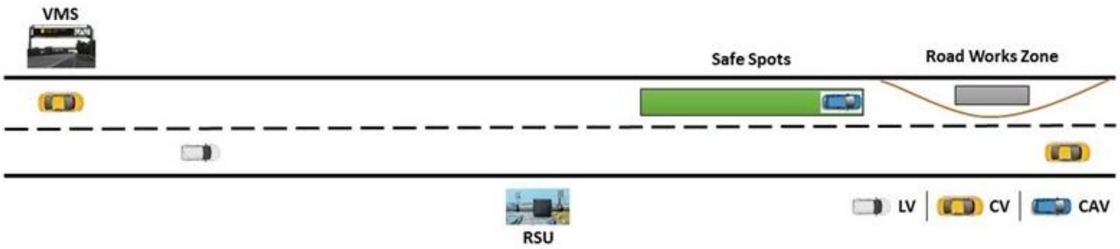

Figure 10: scenario layout of use case 4.2

Use case 4.1+5.1 - Distributed safe spots along an urban corridor

On an urban two-lane road, LVs and C(A)Vs are approaching a no-AD zone, where manual driving is obligatory. Therefore, all C(A)Vs need to perform a transition, which occasionally may fail and lead to an MRM. Without further information, the vehicle would be expected to perform the MRM on the carriage way and interfere significantly with smooth and safe traffic operation. However, upstream of the no-AD zone, several parking spaces are located on the road side, which could be used as safe spots. The RSI monitors the position and speed of the approaching vehicles and the availability of the safe spots (parked vehicles) and provides information about which spot to use in case of an MRM to the CAVs. Furthermore, the RSI will schedule and send ToC advices and safe spot advices to individual CAVs likely to perform MRMs. C(A)Vs that receive a ToC advice will initiate a takeover with a specified lead time. In case that the driver/(remote) operator does not take over within this lead time the vehicle will try to steer towards its assigned safe spot and stop there.

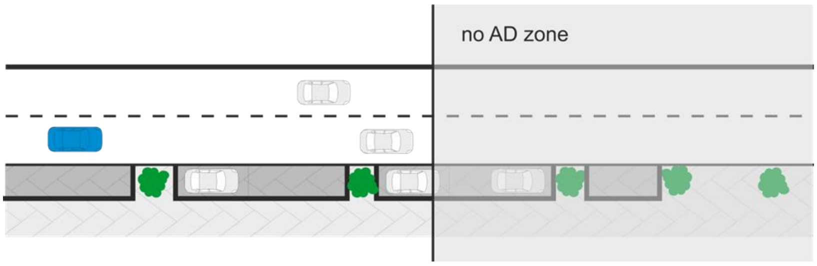

Figure 11: scenario layout of use case 4.1+5.1

Use case 5.1 - Schedule ToCs before no-AD zone

The AD is not allowed in specific traffic areas due to external reasons (e.g., policy, incident, etc.). In these situations, CAVs must perform a ToC upstream of the no-automated-driving zone (no-AD zone) (see Figure 12). This can generate a high number of ToCs in the same area, which can lead to adverse effects for the traffic safety and efficiency. TransAID's service 5 aims at distributing the ToC in time and space over a large area to increase the overall traffic safety and efficiency. In this scenario, the TMC monitors the area upstream of the no-AD-zone and computes a desirable position for the upcoming ToCs of the approaching CAVs. Using this information, the TMC sends individual ToC advices to the CAVs to guarantee that all CAVs are manually driving once they enter in the no-AD zone.

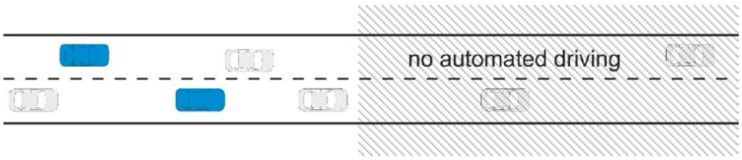

Figure 12: scenario layout of use case 5.1

Appendix B: Overview of action plans for road authorities

Both the MANTRA (Amelink, et al., 2020) and EU EIP (Kulmala, et al., 2020) initiatives created lists of action plans for road authorities in relation to the introduction of automated vehicles. Surveys were held by both initiatives to determine those actions that were deemed most important. Those deemed most important by MANTRA are indicated with a single *, and those by EU EIP a double star **.

The tables below group the different actions in several themes and provide an overview of the actions as described in MANTRA/EU EIP. These tables are for reference only and do not contain input from TransAID apart from minor editing. From these actions, those most relevant to TransAID were selected and reflected upon in section 4.

Physical Road infrastructure

Table 3 details possible actions for the physical infrastructure. For example, (C)AVs ((Cooperative and) Automated Vehicles) require safe havens for performance of MRMs (Minimum Risk Manoeuvres) distributed along the infrastructure. There is also the need for high quality of road markings, signs, equipment.

Table 3: Possible actions for physical road infrastructure

Action	Specification / first steps
Uniform wear of pavement enabled by wheel path alteration in cross-section	Find methods to alter horizontal lane positioning to ensure even wheel path distribution across lanes in a safe manner.
Pavement design and maintenance standards review and adaption (in case of failure of action above)	Study analysis of rutting and fatigue potential in case of increasing unification of wheel paths. Finally make design and maintenance guidelines based on empirical data.
Pavement monitoring and maintenance on truck platooning routes (depends on actions above)	Additional pavement maintenance and strengthening for truck platooning routes
* Additional emergency bays, wide shoulders and safe harbours	Provision of safe harbours in pilot projects and evaluation of necessity. Identify required interval during pilots and ahead of tunnels
*/** Safe minimum risk manoeuvre specification considering also cases of very large AV fleets	Sharing of operational practices; Agreement with OEMs, ADS providers, NRAs and other road operators; Pilots and their evaluation
Safe passenger pick-up and drop-off + EV charging points for automated shuttles and robot taxis	Piloting of different solutions for different road environments. Design passenger access and egress.
** General road design	New definitions such as for visibility distance, inclinations, based on findings in pilot projects.
Ramps and junctions	Determine strategy for merging traffic for both AVs and mixed traffic; e.g., platoons and entry ramps; digital ramp control or cooperative merging.
* Road markings of sufficient retro-reflectivity in different visibility and weather conditions	Definition of specifications or even standards for machine-readability to be regularly reviewed due to AV technology evolution; enhanced maintenance and quality management; mix of physical and digital information on road marking and definition of a clear rule set in case of discrepancies.
*/** Road signs	Wider implementation of the TN-ITS mechanism for the exchange of information on changes in static (i.e., rather permanent) road attributes, from road authorities, who create the changes, to ITS map providers and other users, in support of keeping ITS digital maps highly up to date for such attributes.

Road equipment (gantries, gates, landmarks etc.)	Gates for separated lanes/areas to be installed on pilot project routes and crucial routes. Piloting of landmarks of different types on selected routes (incl. tunnels, fields, forests); potentially slowly decreasing need for road equipment due to digital support
Harmonisation of toll plazas	Toll plazas are quite heterogeneous in their planning and appearance making it possibly difficult for automated vehicles to navigate safely. Hence, harmonisation in the planning and management of toll plazas is likely needed. As driverless vehicles can hardly pay tolls manually at toll plazas, they require an automatic payment lane.
Consider criteria for dedicated lanes	One element that would have a tremendous impact on new road planning standards but also budget is the decision whether or not dedicated lanes should be provided anywhere or for any use case. For obvious reasons it will be neither feasible nor possible to provide dedicated lanes everywhere.

Digital road infrastructure and ITS systems

Table 4 contains the roadmap for digital road infrastructure. In order to support (C)AVs, a digital infrastructure has to be developed and deployed in the form of digital twins and HD maps. Both are dependent on large-scale digitalisation and harmonisation of the road infrastructure. The digital infrastructure should also be maintained, possibly through vehicle data. Moreover, risks have to be mitigated as much as possible for both innovation and cybersecurity. Systems to overcome errors in digital maps are required and lead to potentially new operational strategies. Cooperation between OEMs and NRAs may be required to achieve this, but thinking beyond the traditional ecosystems may be a necessity in this fast and dynamic digital field.

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

Table 4: Possible actions for digital infrastructure

Action	**Specification / first steps**
* HD map processes	Closely monitor processes and achievements in roadmapping activity on HD maps. Agreement of the processes; Specification and setting up of NAPs.
* Provision of data to HD maps	Digitalisation of all public road networks.
* Maintenance of HD maps	Pilots on continuous update based on feedback from sensing systems in CAVs; Investigate options to keep maintenance effort of HD maps within reasonable range.
Accountability in case of mistakes or conflicting interpretation (mistakes will occur)	Explore new roles: in cooperation with OEMs and commercial automated services providers.
Use digital technologies to leverage "shades of knowledge" / less documented yet emerging knowledge in NRAs	Pilots to investigate; Deploy digital infrastructure to leverage emerging knowledge faster / almost near to automated detection.
Use digital technologies to dynamically identify yet emerging new frontiers / unknown unknowns	Cooperation with ecosystem partners in machine learning and AI.

* Cybersecurity issues	Explore risk mitigation in cooperation with other AV-related stakeholders.
Find ways to cope with innovation risks (shorter innovation cycles in digital) (possibly in a commercial role model)	Explore new roles in buying / procurement with shortening innovation cycles as opportunities not as challenge.
Rephrase procurement policies (shorter innovation cycles) accepting that there are several technology options with unclear outcome / significant investment risk	Experiment with adjusting procurement: TRL-based procurement potentially underestimates dynamically evolving digital infrastructure ecosystem.
Rephrase procurement policies towards European digital platform-based ecosystems rather than stand-alone products and services	Look into strengthening European ecosystems in AV / digital infrastructure.
RTK or corresponding land stations	Deployment along selected roads.
Provisions in tunnels	Awareness, research; pilots; Satellite positioning support, connectivity; provisions for two-way traffic during maintenance.
Trunk communications for short range and longer range V2I	Deployment on selected corridors and all new main roads.
Roadside stations for short range V2I	Deployment on selected corridors and hot spots to convey critical information to AVs (e.g., related to ODD).
External indication of being driven by ADS, or being last in platoon to ensure safety & TM	R&I to identify best solution; pilots with evaluation; drafting of specifications.
Road operator fleet supervision centres	Research and limited pilots.
Remote operation centres including questions of "roaming" / cooperation between operation centres	Preparation of legal framework and piloting of some operation.
*/** Use of digital twins for the (road) transport system	Integration of key automation concepts ODD, ISAD and information provision tools (HD Map) under the umbrella concept of the Digital Twin for the road transport system, prototypes demonstrating the viability, pilots starting.
New role from digital twins spin-off. Not only for build and maintain but explicitly for high intensity simulation and traffic flow operation	Development and piloting of related realtime simulation models for high intensity use.
Mandate to provide existing data to HD Maps	Preparation, adoption and deployment.
Mandate for fleet managers and OEMs to provide feedback on HD maps	Discussion and preparation, adoption and deployment.
Strengthen absorptive capacity towards artificial intelligence, digitalisation and automated decision making (might involve a wide role for NRAs)	Build and contribute to a highly innovative, local digital infrastructure ecosystem.
* Human resources in digital expertise	Proactively attract digital expertise and promote challenges and opportunities.
Competitive awareness and potential selective cooperation with big tech companies who have already taken steps into the mobility domain and increase their roles in the digital mobility ecosystem,	NRA's role in network operation and traffic management requires that NRAs are active in the digital mobility ecosystem and proactively maintain their coordinating and supervisory role in their domains.
Product liability issues for digital infrastructure	Research, studies, preparation in pilot contexts.
** Sustainable, long term digital service provision	Digital developments can move very quickly. Any digital service should be sustainable and should function for a long time.
** Appropriate quality assurance methods and processes for data provision	To ensure the quality of traffic information, stakeholders need to use appropriate quality assurance methods and processes. While this is a standard practice for commercial stakeholders, many road authorities and operators do not have such quality assurance in place.
** Supply real-time information on road status and regulations	Real-time information of the traffic status on the road network is necessary for the traffic management centre(s) operating the transport network. They need to know the current and predicted status of the traffic performance on the network in order to select the appropriate

	traffic management actions to ensure the maximally safe and efficient performance at all times.
Make information of traffic signs available via connectivity	Traffic signs are similar to road markings in the ODD evolution. Camera-based sensing requires the signs and signals to be of sufficient quality and clearly visible to be machine-readable, but the information in all permanent signs shall at least be available to all automated vehicles via connectivity.
Supply information on ODD termination risks	ODD-aware traffic managers can also provide information of likely ODD termination risks due to events, incidents, weather forecasts or other issues to the automated vehicles and their automated driving systems. Traffic management of the future may also contain ODD management as one functionality.

Operations and services

Table 5 - Table 10, contain the roadmaps for the different topics within operations and services of the national road authorities.

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

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

Table 5: Possible actions for Incident, event and crisis management

Action	Specification / first steps
* Harmonised marking of incident sites	Studies, standardisation and profiling of the standards on the EU level.
Harmonised management of incident sites	Fine-tuning of processes, deployment pilots.
* AVs will detect and provide information on incidents, e.g., by detecting stopped vehicles and roadway defects	Standardisation and proof of concept. Use of hybrid C-ITS messaging.
* Digitalisation of incident and traffic management plans	Deployment, incl. traffic circulation and traffic mgmt. plans.
Automation of incident warning and rerouting services, e.g., for over-wide vehicles	Studies and pilots; deployment on lower automation level.
Response to emergency vehicles	Studies and standardisation (needs V2V and V2I), pilots and deployment.
Use of safety trailers at incident sites to safeguard clearance	Studies and pilots.
Use of safety trailers and similar to protect moving events	Pilots and early deployment.
* Provision of incident and event management related data to traffic managers and service providers	Studies, agreements and MoUs, pilot deployment, mandating.
Prediction of incidents via AI	Research, pilots, development of business model, deployment.
* Legal adaptations to enable data sharing of safety critical data	Further definitions and harmonisation.
Leading or coordinating role of NRAs & ROs in road incident management	Studies, piloting including by CEDR.
Standardisation concerning the marking and management of incident sites	Standardisation actions need to be pursued concerning the marking and management of incident sites taking into account the capabilities of and requirements towards highly automated vehicles. The compliance to such standards should preferably be mandated, at least on the European level.

Traffic management and control

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

Table 6: Possible actions for traffic management and control

Action	Specification / first steps
*/** Cooperative traffic management concept	Studies and pilots, deployment.
*Digitalisation of traffic management centres	Deployment, including traffic circulation and traffic management plans.
Access control (slots) and/or pricing	Research on feasibility and pilots on relevant networks, deployment.
* Digitalise traffic rules and regulations	Studies, pilots, standardisation; development & standardisation of Trusted Electronic Regulations Access Points (TERAP).
Deployment of geofencing for traffic management	Research, pilots for different orientation (safety, emissions, AVs, Non-AVs…); Deployment by forerunners; Harmonised specifications for TM related geofencing.
Provision of ODD management	Research, agreements and MoUs with OEMs and ADS providers;
Conductor role of road authority/ operator in traffic management (see incident management)	studies, pilots, deployment by forerunners. Maybe EU Mandate No. 3.4 of the Work Programme 2018-2022 of the ITS Directive, i.e., to look into data from vehicles to be shared for purposes of traffic management. Support study EC has been launched and will be finalised end 2020. Delegated Regulation prep to be expected subsequently.
Real-time lane management	Research on principles and possibilities; pilots.
Removal of informative and route guidance road signs – relevant for all vehicles	Research on distraction impacts; inventory of road signs to be potentially removed; Plan for removal in stages.
Flexible roadside stations	Piloting and specifications for flexible roadside stations
Use of digital twins for the (road) transport system	Integration of key automation concepts (ODD, ISAD) and information provision tools (HD Map) under the umbrella concept of the Digital Twin for the road transport system, prototypes demonstrating the viability, pilots starting.
New role from digital twins spin-off. Not only for build and maintain but explicitly for high intensity simulation and traffic flow operation	Pilots of digital twins; Development and piloting of related realtime simulation models for high intensity use.
Issues of human decision making at traffic management centres	Prepare legal ground for automated decision making.
New role: Traffic control room paradigm shift from safety-orientation to optional societal optimum risk management	Study options and feasibility into how new forms of evidence-based management from ubiquitous sensors and data would challenge some dominant role models.

Road and winter maintenance

Table 7: Possible actions for road and winter maintenance

Action	Specification / first steps
Integration of operations management centre and traffic management centre	Definition of data exchange and processes; Integrated processes and communication.
Connected road maintenance zones	Data exchange and definition of standardised processes for temporary maintenance zones; Integrated processes and communication.
* Legal framework for specific use cases of driverless maintenance vehicles	Provision of legal framework for initial use cases like driverless safety trailers, mowing robots.
Procurement of automated winter maintenance vehicles	Pilot projects and test sites for winter maintenance vehicles with advanced driver assistance systems and driverless vehicles for rest areas and other areas without fast moving traffic.

Traffic information services

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

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

Table 8: Possible actions for traffic information services

Action	Specification / first steps
* Standard AV-suitable comm protocols with TMC, fleet managers, service providers and automated vehicles	Development of standardised communication protocols, and use of sensors. Need of AV specific messages?
* Provision of hybrid C-ITS traffic information services	Specs & profiling of hybrid C-ITS traffic info services; large scale piloting; guidelines for use; deployment and use by forerunners.
Enhancing traffic information content	Research on optimal, smart traffic system level optimised routing and guidance.
* Improving information quality	Development and take-up of quality assurance processes for traffic information.
*Quality assurance and assessment of data	Development of processes and techniques for the data chain
*Sharing of data and storage of data (note: also relates to Enforcement)	Agreements between stakeholders, deployment of SRTI; Define categories of incidents; Pilots (note the Data Task Force PoC (Proof of Concept); Mandating the sharing of safety related and traffic management related data.
Harmonisation of pictograms and messages (including messages in text)	Discussion and hopeful agreement between stakeholders; Standardisation of pictograms for warnings and regulatory information
Use of digital twins for the (road) transport system	Integration of key automation concepts (ODD, ISAD) and information provision tools (HD Map) under the umbrella concept of the Digital Twin for the road transport system, prototypes demonstrating the viability, pilots starting.
* Security of data	Security and privacy of low-level data. Access to data for environmental management and enforcement.

Enforcement

Table 9: Possible actions for enforcement

Action	Specification / first steps
* New infrastructure and regulations for traffic law enforcement, including for conventional vehicles	Connected speeding cameras with necessary accuracy still needed for human operated vehicle.
Enforcement through weigh-in-motion systems	Tests of necessary accuracy of WIM systems; preparation of legal framework for enforcement and requirement to use WIM.
* Tamper prevention	Monitoring of tampering activities; Development of effective prevention and mitigation measures.
* Environmental enforcement	Regulation of data exchange of environmental information of vehicles with infra for geofenced areas. Upgrade of CCTV for identification of environmental vehicle categories where necessary. Preparation of legal framework for enforcement.
Wrong way and tunnel driving detection and enforcement; routing enforcement	Automated vehicles to detect the wrong way driving and share the information with predicted location to enhance safety; piloting.

Road user charging

Table 10: Possible actions for road user charging

Action	Specification / first steps
Implementing of physical measures possibly required by highly automated vehicles on toll plazas	Development and agreement of physical measures.
Marking of toll plazas for highly automated vehicles	Development and agreement of standardised markings and guidance.
Definition of a pricing policy for highly automated vehicles	Research followed by a policy definition (possibly on a European level).
Inclusion of road use charges into HD maps	Specifications: development and agreement concerning dynamic charging.
Update of concession agreements	Negotiations and agreement on how the pricing policy are applied on the concession network.

Planning, building and heavy maintenance

Table 11 - Table 13, contain the roadmaps for the different areas within planning, building and heavy maintenance.

New roads planning and building

Table 11: Possible actions for new roads planning and building

Action	Specification / first steps
Road categorisation ISAD levels also for digital and physical infrastructure	Further specification and official introduction of ISAD levels for digital and physical infrastructure; Consideration of vehicle sensor evolution in further development of infrastructure specifications.
Provision of digital twin and digital data of new road	BIM approach and data structure to be clearly defined and applied already in planning of all new roads planning.

Road works management and planning

Table 12: Possible actions for road works planning and management

Action	Specification / first steps
* Standardised communication protocols with TMC, fleet managers, service providers and automated vehicles	Development of standardised communication protocols, work zone layouts and use of sensors.
* Provision of hybrid C-ITS road works warnings	Specification and profiling of hybrid C-ITS road works warnings; pilots; guidelines for use; deployment and use by forerunners.
* Harmonised marking of road works sites	Studies, standardisation, profiling of the standards on the EU level.
* Harmonised management of road works sites	Fine-tuning of processes, proposal for harmonisation.
Use of safety trailers at road works to ensure safety	Studies and pilots.
** Use of automated vehicles to monitor the performance of road works management	Research, studies, pilots; specification of processes; deployment by forerunners.

Heavy maintenance planning

Table 13: Possible actions for heavy maintenance planning

Action	Specification / first steps
Use of digital twin and digital data of new road for heavy maintenance planning	BIM approach and data structure to be clearly defined and applied already in planning of all new roads planning.

New approaches to road condition data collection for deterioration monitoring	Pilot projects for sensors collecting road surface condition data (rutting, skid resistance, etc.) further development of algorithms for deterioration models.

Possible investments

Table 14: Possible investment actions

Action	Specification / first steps
** Develop investment scenarios for road side systems vs smart vehicles. What is needed in light of evolution of automated vehicles?	No additional specification.
Consider investing in roadside equipment where needed for road authority purposes and others do not	No additional specification.
Prepare to invest to support the ODD but be very selective	No additional specification.

Organisational, role, process

Table 15: Actions regarding organisational, role and process aspects

Action	Specification / first steps
Processes to ensure landmarks will be consistently visible	No additional specification.
** Clarification of roles of stakeholder to ensure industry has incentives to design automated driving systems with road safety as a key	No additional specification.
Determine road authority role in vehicle type approval	No additional specification.
Include smart mobility in traditional road decision process	No additional specification.
Legal framework to allow researchers to analyse and audit while reasonably preserving industry interests	No additional specification.
Prepare for ODD requirements discussion in winter conditions	No additional specification.
Consider role of road authorities in ODD management	No additional specification.

New business

Table 16 contains the roadmap for new core business. The core business areas of national road authorities are in most countries determined by national laws, affected by European legislation. Hence, changes in national or European legislation can result also in the need for the national road authorities to take up new business areas. It might also happen that the evolution of the mobility and transport landscape changes so that there is a need for an organisation such as a national road authority or road operator to assume a new role and task in the mobility or transport ecosystem, resulting in a new business area for the road authority/operator. In both cases, it would be fruitful to consult CEDR and other road authorities and operators, which have already looked at and perhaps even carried out such tasks.

Table 16: Possible actions for new business

Action	Specification / first steps
Adopting new business areas when necessary	Develop and adopt new business areas due to changes in legal framework on the EU and national level or reorganisation on the national or regional level making it necessary to adopt a new role and/or task. The practices in other countries and regions should be considered in the process.
Adopting new business areas when appropriate	Develop and adopt new business area due to the needs of the transport and mobility system for the national road authority to adopt a new role and/or task. The practices in other countries and regions should be considered in the process.
** Launch pilots that include societal focus to get a better understanding of costs and benefits	No additional specification.
** Find business models considering that the actors benefitting might not be the same as the one bearing the costs	No additional specification.