Traffic Management for Connected and Automated Driving (TM4CAD)

Implementation aspects of Distributed ODD attribute Value Awareness

Deliverable D4.1 Version 1.0

March 2023

Consortium partners: MAP traffic management (the Netherlands), Traficon (Finland), Transport & Mobility Leuven (Belgium), WMG, University of Warwick (United Kingdom), Steven Shladover (independent consultant) and Keio University (Japan).

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Executive summary

Safe, efficient, and clean automated driving requires connectivity and exchange of information between automated vehicles and the infrastructure including traffic management centres (TMCs) operating in practice the road network and most of the related physical, digital, and operational infrastructure. The objective of this report is to provide a practice-oriented perspective, based on the Distributed ODD attribute Value Awareness (DOVA) concept applied to the context of NRAs and made more concrete and tangible for specific situations.

The DOVA framework enables the ADS to benefit from off-board sensing infrastructure and data sources to become aware of ODD attribute values which it may not be able to measure or sense by itself. Typically, the earlier the information is available, the more options are possible for the ADS to respond (operational, tactical, strategic).

Current ADS immaturity causes a lot of uncertainty for road authorities as they cannot decide with confidence what is the best way to anticipate ADS development and deployment to preserve operational safety and efficiency on their road network. Typically, the actual competencies of ADS in the operating environment are not entirely known and ADS capabilities are regularly overestimated or underestimated based on assumptions that are derived from the scarce information that is publicly available. At the same time, many different situations can occur on open roads and in variable traffic and weather conditions, in particular when these roads are dynamically managed by the road operator (e.g. lane, speed and tunnel management). It is natural that NRAs are concerned about the introduction of ADS that execute the complete dynamic driving task. The most constructive and perhaps only way forward is to create a dialogue between road authorities, automation system developers and regulators.

This report provides the reader with the relevant background information to better understand the basic principles of ADS system deployment and the role of different actors in the DOVA framework. A few of these principles include:

1) Traffic management systems will not actively manage the tactical or operational decision making of ADS, i.e. activate and de-activate automation, instead its added value to ADS and thereby traffic safety lies in improving the situational awareness of ADS and providing strategic guidance;
2) The driving rules and expected driving behaviour must be defined in regulations such as the Vehicle General Safety Regulation and UN Regulations;
3) Information beyond the line-of-sight of vehicle sensors is relevant for timely anticipation of the downstream conditions. This is where NRAs support ADS the most today, by providing information in advance.

A decision-making flow diagram is provided which aims to support NRAs in the conversation with automation system developers and regulators, and to break down any use case assessment in smaller elements. In addition, detailed descriptions of four use cases are provided: (1) adverse weather conditions, (2) road works, (3) traffic jam and (4) tunnels, each in turn divided into multiple scenarios. Due to the structured way the use case scenarios are described their commonality becomes visible. Roughly in each scenario an ADS receives in-advance information about a local condition further down the road. As the ADS is informed about the local condition and the (detailed) characteristics of the condition, the ADS assesses the situation. Consequently, it can timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS is able to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.

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List of acronyms

Acronym	Definition
ADS	Automated Driving System
AIM	Asset Information Modelling
ALKS	Automated Lane Keeping System
AV	Automated Vehicle
AVG	Automated Vehicle Guidance
BIM	Building Information Modelling
BSI	British Standards Institution
C2C-CC	Car-to-Car Communication Consortium
CAD	Connected and Automated Driving
CAM	Cooperative Awareness Message
CAV	Connected Automated Vehicle
CCAM	Cooperative Connected Automated Mobility
CEDR	Conference of European Directors of Roads
CEN	European Committee for Standardization
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
CRF	CAV Ready Framework
C-V2X	Cellular Vehicle-to-Everything (communication)
DENM	Decentralized Environmental Notification Message
DG	Directorate General
DOVA	Distributed ODD attribute Value Awareness
DOM	Dynamic ODD Management
DoRN	Description of Research Needs
DSRC	Dedicated Short Range Communication
EIP	EU ITS Platform
ETSI	European Telecommunications Standards Institute
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human Machine Interface
I2V	Infrastructure-to-Vehicle (communication)
ICT	Information and Communication Technology
ISAD	Infrastructure Support for Automated Driving
ISO	International Standardisation Organisation
ITS	Intelligent Transport Systems
IVIM	In-Vehicle Information message
L3	Level 3 (driving automation)
L4	Level 4 (driving automation)
LTE	Long Term Evolution
M2M	Machine-to-Machine
MAPEM	MAP Extended Message
MCDM	Multimedia Content Dissemination Message
MCM	Maneuver Coordination Message
MRC	Minimal Risk Condition
MRM	Minimal Risk Manoeuvre
NRA	National Road Authority

Acronym	Definition
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PAS	Publicly Available Specification
RLT	Road and Lane Topology
RQ	Research Question
RSI	Road Side Infrastructure
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SPATEM	Signal Phase and Timing Extended Message
TM4CAD	Traffic Management for Connected and Automated Driving
TMC	Traffic Management Centre
ToC	Transfer of Control
TOD	Target Operational Domain
TRP	Transnational Research Programme
TTI	Traffic and Traveller Information
UN	United Nations
V2I	Vehicle-to-Infrastructure (communication)
V2X	Vehicle-to-Everything (communication)
VRU	Vulnerable Road User
WIM	Weigh in Motion
WP	Work-package

1 Introduction

1.1 TM4CAD

TM4CAD explores the role of infrastructure systems in creating ODD (Operational Design Domain) attribute value awareness for Connected and Automated Driving (CAD) systems. As a starting point we proposed various approaches for providing distributed ODD attribute information and defined acquisition principles of the information based on exchange among the stakeholders, ultimately to enable CAD systems to be aware of their ODD in real-time. Moreover, TM4CAD has demonstrated the basic mechanisms of ODD management via real-world use cases, which build on the premise of interaction between traffic management systems and CAD vehicles. This provides NRAs and other traffic managers insight into methods to inform CAD systems about the kinds of support they can provide for CAD operations on European roads.

To gain a complete understanding of traffic management for CAD, the TM4CAD project:

- Identified the full range of ODD attributes for consideration, based on experience from working on ODD issues in standardization activities and in other related research projects;
- Integrated the very different perspectives of the CAD vehicle system developers and the road authorities and operators to focus on the overlapping areas;
- Introduced the concept of ODD attribute value awareness and the role of infrastructure in it;
- Developed recommendations based on the technical constraints of the ODD-relevant information that can be perceived and exchanged in real time by the NRAs and the sensing systems of the CAD-equipped vehicles;
- Provided insights on how to support CAD operation and ODD management, and how ISAD (Infrastructure Support for Automated Driving) should be refined for traffic management use, and
- Detailed how traffic management systems and CAD vehicles can best interact to improve traffic operations.

Figure 1: *TM4CAD project team members*

The project is carried out by a consortium led by MAP traffic management (MAPtm) from the Netherlands. Other members of the consortium are Traficon (TRA, Finland), Transport & Mobility Leuven (TML, Belgium), WMG, University of Warwick (WMG, United Kingdom), Steven Shladover (independent consultant), and Keio University (Japan).

Team members left to right, top: Sven Maerivoet (TML), Risto Kulmala (TRA), Steven Shladover, Ilkka Kotilainen (TRA); bottom: Jaap Vreeswijk (MAPtm), Siddartha Khastgir (WMG), Anton Wijbenga (MAPtm). Not on the picture: Hironao Kawashima (Keio University) and Tom Alkim (MAPtm).

1.2 Objectives and scope

Safe, efficient, and clean automated driving requires connectivity and exchange of information between automated vehicles and the infrastructure including traffic management centres (TMCs) operating the road network and most of the related physical, digital, and operational infrastructure. The objective of this report is to provide a practice-oriented perspective, based on the Distributed ODD attribute Value Awareness (DOVA) concept applied to the context of NRAs and made more concrete and tangible for specific situations. Implementation considerations and challenges are discussed on a functional level and on the basis of example use cases. This illustrates how new traffic and AV management concepts can be implemented by NRAs with acknowledgment of governance differences among NRAs across Europe.

The research conducted in the TM4CAD project is funded by the Conference of European Directors of Roads (CEDR) Transnational Research Programme (TRP) Call 2020 Impact of CAD on Safe Smart Roads. This call's research objectives addressed three topics: digital infrastructure (incl. digital twins), connectivity and traffic management. Where TM4CAD focusses on the latter, the DiREC project covers the first two topics. DiREC aims to establish a CAV-Ready Framework (CRF) based on a level of service approach to understand the needs of CAD, and to define the infrastructure and services that NRAs could provide to support these needs (DiREC, 2022). Examples of expected results from the DiREC project are:

On digital infrastructure (selection):

- Establish what the NRA goals are in the creation of a digital twin, what the current state of the digital twin is at all NRAs and based on this establish a (common?) roadmap for NRAs in the implementation of a digital twin.
- Establish whether there is a need for the introduction of service level agreements between OEMs and NRAs about the digital twin.
- Establish how NRAs and industry can enter a dialogue on how to exchange information and learn from each other on occurred near misses, incidents and accidents, similar to such dialogues in other industries.

On connectivity (selection):

- Identify the potential roles of NRAs in the field of connectivity and the benefits to an NRA.
- Identify what an NRA needs to do to react to insufficiency, low quality and/or gap in accuracy, connectivity or bandwidth on the network.
- Identify the expectations from OEMs, NRAs, public transport providers and other stakeholders in the field of connectivity and accuracy.

Since these topics are addressed by DiREC in their deliverables, this report will not specify digital infrastructure and connectivity aspects. These topics are considered out of scope for TM4CAD. Nevertheless, some of the views and expectations provided in this deliverable can be considered requirements for digital infrastructure and connectivity. We believe that in order to maximise value for CEDR, exchange of views and results between both projects is valuable and can help NRAs to achieve convergence and establish a common position.

1.3 Research Questions and Expected Outcomes/Outputs

This WP aims to provide responses to the following research questions (RQ) of the Call:

***Table 1**: mapping of Research Questions to Deliverable 4.1*

Research Questions	**Addressed in**
RQ2: Do brokers between traffic management centres and vehicles/OEM back ends add value in this interaction?	Section 4.2 and 5.2
RQ3: How does CCAM support the work of traffic management centres and how can traffic management centres support and facilitate the deployment of CCAM?	Section 3.4 and chapter 5
RQ6: When and how should such information be available?	Chapter 2, section 4.1 and chapter 5
RQ8: Are there any circumstances under which the traffic control centre would need to lower the ISAD level in order to stop automation taking place, or vice versa: to impose automated driving?	Sections 1.4, 3.2 and chapter 5

***Table 2**: mapping of Essential Results to Deliverable 4.1*

Essential Results	**Addressed in**
ER1: Determination of the circumstances (actual traffic conditions, status of the infrastructure, …) under which the traffic control centre would need to lower the ISAD level in order to stop automation taking place and accordingly mitigating measures if applicable	Chapter 2 and 5
ER2: Determination of the circumstances under which the traffic control centre would need to upscale the ISAD level/impose more automated driving	Chapter 2 and 5
ER5: Definition of the roles and responsibilities in the interaction between OEMs/Service Providers and NRAs on operational level	Sections 4.2 and 5.2

***Table 3**: mapping of Optional Results to Deliverable 4.1*

Optional Results	**Addressed in**
OR1: Description of the possible added value of service providers in the interaction between NRAs and OEMs;	Sections 4.2 and 5.2

1.4 Relationship with other Work Packages

This report builds on the results from WP2 on Distributed ODD attribute Value Awareness and WP3 on information needs, quality and governance. The primary results of these work-packages are summarised below. This report adds more concrete examples and implications for day-to-day operations as well as implementation aspects relevant to NRAs.

In addition, the work leading to this report has utilised the results of projects like INFRAMIX, TransAID, C-Roads and MANTRA plus experiences and insights from American and Japanese deployments.

1.4.1 WP2: Distributed ODD attribute Value Awareness framework

The need to monitor or be aware of each ODD attribute puts an additional overhead on the Automated Driving System (ADS) to be able to measure each ODD attribute. However, measuring each ODD attribute may not be practically feasible from a cost and engineering perspective so ODD attribute value awareness is key to ensuring safe operation of the ADS. In order to overcome this challenge, TM4CAD has introduced the concept of Distributed ODD attribute Value Awareness (DOVA) framework (Khastgir et al. 2022).

The DOVA framework enables the ADS to benefit from off-board sensing infrastructure and data sources to become aware of ODD attribute values which it may not be able to measure or sense by itself. For example, an ADS may not be able to detect the severity of a visibility impairment from a fog bank that it is approaching. It may be able to receive such information from a roadside weather station which can provide this information through over the air communication with the ADS. This enables the ADS to have awareness of this current operating condition and compare it with its designed ODD to establish if the ADS is inside or outside its ODD. Typically, the earlier the information is available, the more options are possible for the ADS to respond (operational, tactical, strategic). Reversely, if the ADS cannot become aware in case attribute value information is unavailable, it means that it is unsafe and therefore not possible to operate.

While information for some of the ODD attributes could be available via public infrastructure, there may also be commercial services which can augment ODD information for the ADS.

From a National Road Authority (NRA) perspective, it is important to establish what type of ODD attribute information should be provided via infrastructure and its corresponding quality to enable safe deployment of ADS. It is also important to consider the needs of the NRAs and traffic managers to be aware of any ADS approaching the boundary of their ODD and/or being in a transitional or minimal risk state.

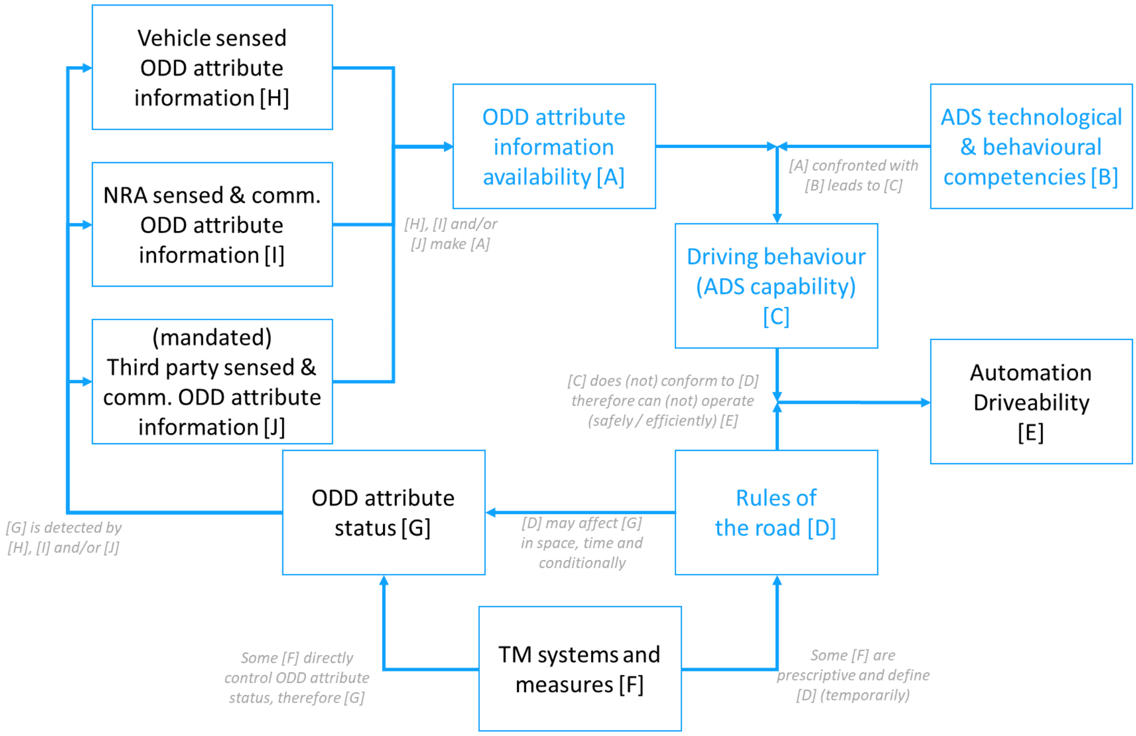

Figure 2*: Distributed ODD attribute Value Awareness framework (source: Khastgir et al, 2022)*

The operation of the DOVA framework in practice is illustrated in **Figure 2**. The ODD attribute information (or from the road operator perspective local condition attribute information) sharing plays a major role in influencing the driving behaviour of the ADS-operated vehicle depending on its technical capabilities and the rules of the road. The traffic management operations affect the rules of the road (i.e., the expected behaviour) as well as the status of the ODD / local condition attributes sensed by the vehicle, the road operators' and other stakeholders' monitoring and other data acquisition systems providing the attribute information to the ADS-operated vehicles and other road users.

1.4.2 WP3: information needs, quality and governance

When considering the exchange of information between traffic management centres and automated vehicles, it is essential that both the automated vehicles and TMCs receive the relevant information in time and with the quality and service levels needed. The WP3 report (Kulmala et al. 2022) describes the information needs of three actors (automated driving system developers/OEMs, traffic managers and road works/maintenance operators) in three scenarios: traffic jam, adverse weather area and road works zone for SAE Level 3/4 vehicles on highways and motorways.

The information attributes were prioritised based on their importance to the various stakeholders as well as safety criticality. The priorities were validated via an online survey and workshop organised for vehicle manufacturers and a workshop for CEDR members. In total, seven physical infrastructure, eight digital infrastructure support, sixteen ambient environmental conditions, and nine operational roadway condition related local condition attributes were regarded as having highest priority for ODD attribute value awareness.

Methods, processes and standards for the exchange of the data within the DOVA framework were described to reach a feasible practical solution for harmonised data exchange. Further, issues in the governance of the DOVA were discussed in the light of recent experiences from European actions with regard to road safety related data and national access points. The management and hosting of the DOVA framework are addressed specifically. The most promising solution is likely a neutral third party, trusted by all stakeholders and mandated to act as an information and data collection and clearing house. This could take the form of a public-private partnership, in which the government also commits itself to providing information and data according to pre-agreed specifications. Trust of information sources, information maintenance and governance of the ecosystem were highlighted as the most pressing open issues.

To better understand the possible evolution of DOVA, three potential scenarios were presented for information acquisition divided over on-board and off-board sensing. In the near term, while the infrastructure is not yet ready to provide ODD attribute information, we foresee that all information will be obtained through on-board sensing. This has also been confirmed by CAD system developers in our surveys. We don't foresee a situation in which all of the sensing is in the infrastructure. Therefore, scenario 2 will not be applicable, even in the long term.

	On-board sensing	**Off-board sensing**
Scenario 1	100%	0%
Scenario 2	0%	100%
Scenario 3	X% (where X ≠ 0)	(100 – X) %

In the future, scenario 3 will likely be the dominant one. The TM4CAD project's focus is to develop a better understanding of scenario 3 and identify the key enablers to bring it to reality and a decision-making process for understanding "X%" and the content of the ODD attributes in the "X%". It is important to recognize that X is not a fixed value, but rather it will vary by location and time, based on differing needs and capabilities in different countries, The decision-making process that was introduced in the WP3 report is shown in the figure below. As part of this handshake process, an agreement would be achieved between the two stakeholder groups on both the number and types of the ODD attributes provided by (infrastructure or off-board systems) / sought by (CAD system developers) and the quality metrics for each attribute.

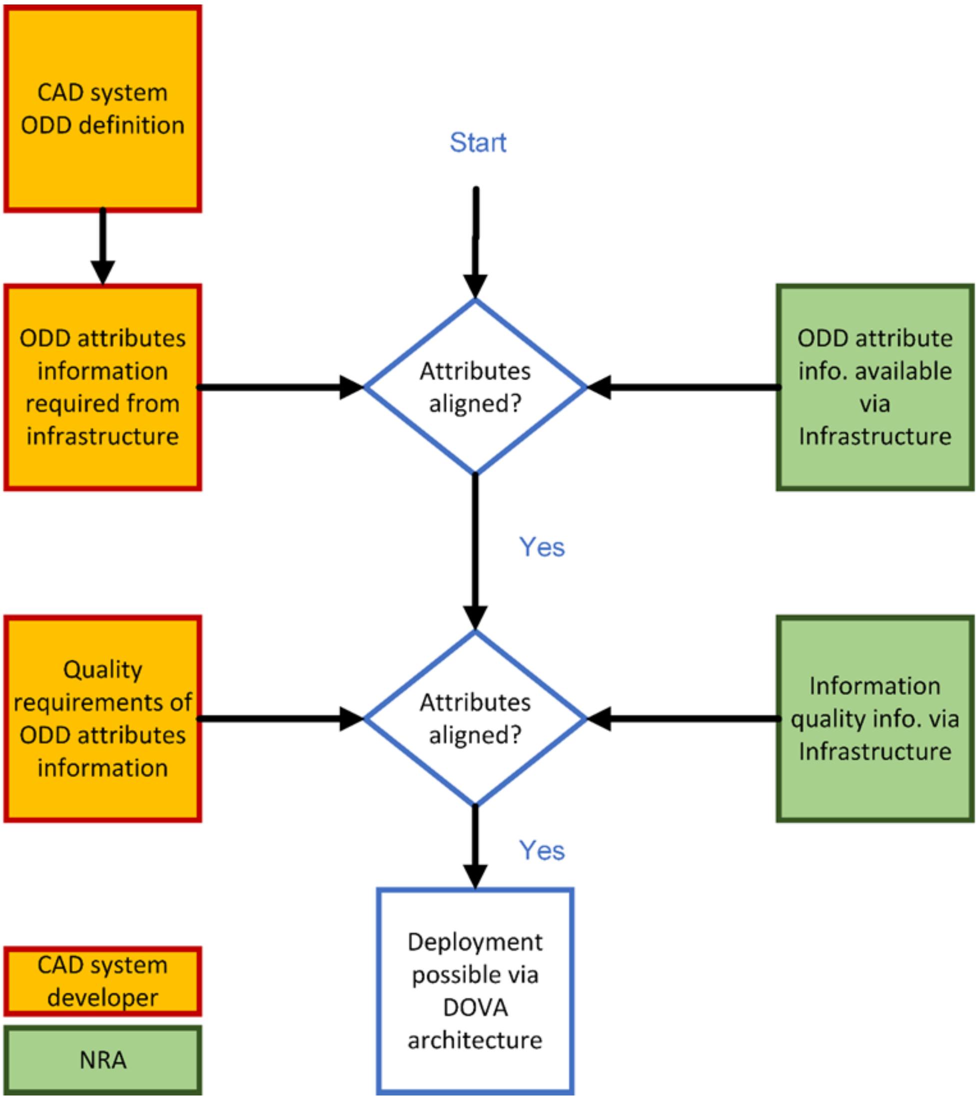

***Figure 3**: logic flow for decision making process for implementing DOVA (source: Kulmala et al, 2023)*

1.5 Use cases and concepts

Use case descriptions are a useful instrument to gain a common understanding of the expected and desired behaviour of a (automated driving) system in a specific situation and the role of involved actors in different scenario flows. Traffic management for connected automated vehicles is largely about the exchange of information between traffic management centres and automated vehicles. This is also the main premise of the Distributed ODD attribute Value Awareness framework.

NRAs may have different motives to contribute to use case development, these could be:

- Traffic safety, which is a short term interest regarding the safe introduction of ADS, primarily to avoid unsafe and unexpected driving behaviour and too many (late) disengagements;

- Facilitating driving automation, which is a medium term interest anticipating the safety and efficiency benefits that ADS are expected to bring over time. This entails supporting the safe operation of ADS by assisting the ADS to overcome technological limitations;
- Active traffic management, which is a longer term interest built on the premise of better compliance of vehicles through ADS which will enable NRAs to better manage traffic volumes and traffic flow dynamics.

At the same time, NRAs have expressed concerns with regards to the behaviour of ADS on their roads, especially in case of unplanned and unexpected situations that may lead to a takeover request or a minimal risk manoeuvre. The worst case image in the mind of NRAs is an automated vehicle that comes to a full stop in a driving lane. To better understand the likelihood of this occurrence and the precise scenario flow, use case descriptions are needed. These address the concerns of NRAs which roughly are related to:

- Locations; these are pre-defined road sections such as tunnels, merging areas, road work zones which are precarious on their own and are expected to challenge ADS;
- Conditions; these are local situations in an area or road section which challenge perceived or known operational limitations and/or safety risks for ADS;
- Location-conditions; these are (pre-defined) locations that require extra attention when certain conditions are present (e.g. darkness, heavy traffic, narrow lanes).

In section 1.6 of the WP3 report (Kulmala et al. 2022) three use cases are presented based on the priorities indicated by NRAs. The use cases involved two different ADS: Level 3 Automated Lane Keeping System (ALKS) or Traffic Jam Chauffeur and Level 4 Highway Auto Pilot. Three different driving environments were considered: traffic jams, adverse weather conditions and road works. This report will provide additional context to these use cases and others.

As a start it is interesting to take notion of results from the projects INFRAMIX, TransAID, and C-Roads. These projects have described and built their work on a number of use cases. The INFRAMIX project designed, developed and evaluated solutions for automated vehicle deployment in mixed traffic for three different situations:

- *Dynamic lane assignment* (incl. speed recommendations);
- *Construction site / roadworks zone*;
- *Bottlenecks* (on-ramps, off-ramps, lane drops, tunnels, bridges, sags).

The TransAID project had a slightly different approach as instead of placing situations at the centre, the project focussed on *services* that can be delivered by infrastructure to support ADS. The reason for this approach was the uncertainty related to ADS capabilities in different situations and not knowing the presence or absence of which ODD attributes causes disengagement of ADS. The idea was that the services are situation-agnostic and serve as generic solutions to prevent issues around ODD edge cases. Depending on the cause for ODD departure one or more of these services can be applied to the situation to mitigate negative impact of ODD departure. Five services were defined (Wijbenga et al. 2018):

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 a ToC/MRM due to complex traffic situations emerging from either planned or unpredictable events;

3. *Prevent ToC/MRM by traffic separation*; different vehicle types 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 a 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.

Lastly the C-Roads project, which is a platform for harmonisation of C-ITS deployment in Europe, has included two automated vehicle guidance use cases in the document for C-ITS Service and Use Case Definitions (C-Roads platform, 2022). The use cases are summarised in the C-Roads report as follows:

1. *SAE automation level guidance*: the purpose of the use case is to provide guidance and information on the SAE levels of automation road operators consider unsuitable for partly automated vehicles on certain road or lane segments on their network, at a given point in time, considering overall road conditions and the current traffic situation.

2. *Platoon support information*: the purpose of the use case is to provide road operator-based guidance and information on the suitability of "platooning" on specific road or lane segments on their network, considering different vehicle classes, overall road conditions and the current traffic situation. A platoon is a group of vehicles travelling closely together at a common speed. Platooning situations can involve different vehicle classes, including trucks or cars.

It is important to note that the basic principles assumed by the C-Roads platform are different from those considered by TM4CAD, especially with regard to SAE Level Guidance. It is our understanding that the decision to operate in the current local conditions is entirely up to the ADS based on the situation awareness the system has to that moment. Interestingly, the disclaimer in the C-Roads report as part of the use case summaries seems to imply a distributed attribute value awareness concept as was defined in Khastgir et al., 2022:

"It aims to be an additional piece of information for the vehicle's decision-making process while engaging in modes of automation, transporting the road operator's view into the vehicle. This can result in an increase / decrease of functionalities required from the automated vehicle and a corresponding decrease / increase in what is required from the driver, based on the overall traffic situation, the sensory input from the vehicle itself and the message received by the infrastructure. The use case as a whole is strictly guidance and never to be understood as regulation or instruction. Any guidance provided is not a road operator's guarantee for safe operation of certain modes of automation nor is it a definitive statement that certain modes of automation are possible or impossible, allowed or not allowed."

1.6 Structure of this document

This deliverable is organised in the following manner. Chapter 2 distinguishes different types of local conditions and how these relate to ODD departure. Next, chapter 3 describes the responses of CAD systems to DOVA information, the time dimension of information availability and how NRAs may benefit from CAD systems signalling their minimal risk manoeuvres. In chapter 4 we discuss data sources and communication technologies as well as possible organisation structures. Thereafter in chapter 5, a decision-making process for NRAs is provided followed by an actor landscape and four use case descriptions. Chapter 6 provides an outline of opportunities for NRA and TMC core businesses and is followed by the Conclusion section.

2 Understanding events during CAD system deployment

2.1 *Introducing ODD boundaries and their importance*

For safe operation of any CAD system, it is essential to be able to accurately define and establish the ODD boundaries of the CAD system. ODD defines the operating conditions within which the system is designed to operate, being able to operate safely within a system's ODD is crucial. At a high-level, ODD contains the physical attributes (such as road, junctions, road structures), the environmental conditions (such as rainfall, snowfall, wind), and the dynamic conditions (such as types of agents, prevailing traffic speed). In order to operate within its defined ODD, the CAD system needs to be aware of the boundaries of the ODD as defined at the time of system design to establish system's ODD departure.

It is important to highlight that such an ODD departure needs to be an objective definition. At any instance, the CAD system can either be inside its ODD or outside its ODD. There shouldn't be any confusion about the state of the CAD system with respect to comparing its current operating conditions with its defined ODD. In other words, as the CAD system will be comparing the current operating conditions (i.e., real-time deployment area) with its ODD definition, it should reach a Boolean decision on whether it is inside or outside its predefined ODD.

Such an ODD departure definition is not only required for safe operation of the CAD system, but also for understanding the safety assurance process of the CAD system considering scenario generation for real-world and virtual testing. From an NRA perspective, such information needs to be part of the initial approval process for the CAD system to deploy.

2.2 *Types of ODD departure condition*

Depending upon the characteristics of the "ODD departure condition", the condition can be classified along two axes:

- **Predictability based:** This type of ODD departure condition suggests whether it is planned or unplanned.
- **Location based:** This type of ODD departure condition suggests whether it happens at a fixed location or at a variable/temporary/moving location.

It is important to highlight that a planned ODD departure condition can occur at a variable location (e.g., roadworks). Figure 4 illustrates various possibilities (with some illustrative examples) of different types of ODD departure condition.

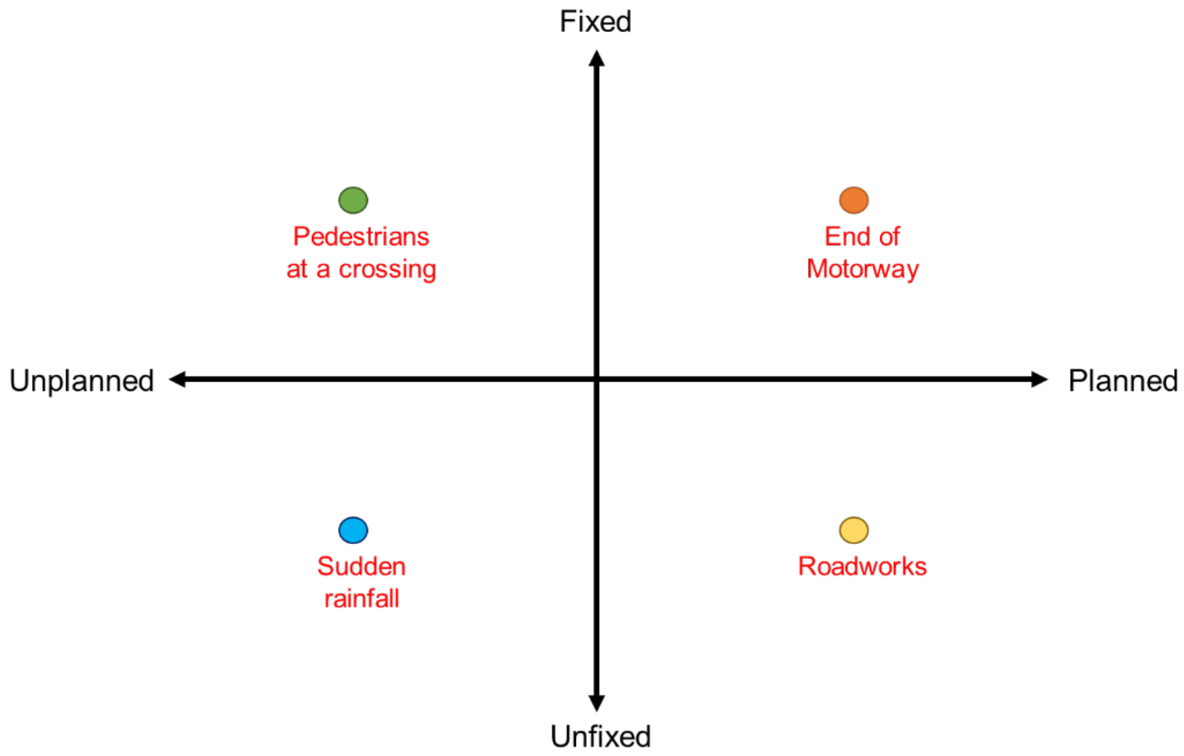

***Figure 4**: types of ODD departure conditions*

2.2.1 Temporal nature of ODD boundary violation

In order to achieve an objective definition of an ODD departure condition, we need to first be able to specify an accurate and realistic ODD definition. An ODD definition constitutes statements regarding inclusion, exclusion, and mutual dependence of different ODD attributes. While comparing real-time conditions with each ODD attribute can contribute to ODD departure condition, an ODD definition is only formed once all ODD attributes are considered together.

An ODD departure condition could be triggered if the real-time conditions violate any of the predefined ODD attribute values. However, it is important to highlight that instantaneous or momentary violation of any ODD attribute may not (and most probably should not) be construed as an ODD departure that would immediately trigger a minimal risk manoeuvre (MRM). Traditional ODD concepts and definitions have not considered the role of time in the context of ODD departure condition.

In order to better illustrate this concept, we first address the need for appropriate ODD definitions. Figure 5 below illustrates an example ODD definition.

For each combination of ODD attributes, it is possible to create an ODD departure scenario/situation that should trigger a fallback or an MRM. In any real-world deployment, it is reasonable to expect an ODD departure condition being triggered due to the violation of any of the ODD attributes. However, prudent ADS developers provide tolerance margins on their ODD boundaries so that corrective actions can be taken before the ADS reaches situations in which it is no longer able to safely control vehicle motions.

```
Include: BSI PAS 1883: 2020 Operational Design Domain (ODD) Taxonomy
for an Automated Driving System (ADS)
Base state: Permissive
Extension: Add median crossover to drivable area type

#Composition statements
Cond_1 Conditional drivable area type is [motorway, radial roads, distributor roads]
Cond_2 Conditional drivable area type is [median crossover]
Included number of lanes is [1,∞]
Included lane dimension is [3.7,∞]
Excluded roundabouts are [all]
Excluded intersections are [grade separated]
Cond_3 Conditional horizontal plane is [curved roads]
Excluded special structures are [all]
Included direction of travel is [right hand drive]
Included lane type is [traffic lane]
Included drivable area surface type is [asphalt, concrete]
Excluded fixed road structures are [buildings]
Excluded drivable area edge is [None]
Excluded transverse plane is [pavements]
Included temporary road structures are [road signage]
Cond_4 Conditional temporary road structures are [refuse collection, road works]
Excluded rainfall is [light rain, medium rain, heavy rain]
Excluded snowfall is [heavy snow]
Excluded particulates are [mist and fog]

#'Conditional' statements
Cond_1 Included speed of subject vehicle for [motorway, radial roads, distributor roads] is
[0,15 km/h]
Cond_2 Included drivable area signs for [median crossover] are [yield, stop, one-way, do not
enter]
Cond_3 Excluded radius of curved_road is [0,13 m]
Cond_4 Excluded location of [refuse collection, road works] is [in lane]
```

***Figure 5**: example of ODD definition*

Here we would like to point out that for each ODD attribute, the ODD departure condition can occur:

- **In a planned manner:** This suggests the predictability of the ODD departure condition based on prior knowledge of the CAD system, e.g., motorway exit information via digital maps)
- **In an unplanned manner:** This suggests the unpredictability of the ODD departure condition as per the sensing capability of the CAD system, e.g., sudden detection of dense fog.

To illustrate this concept further, let's take an example of the "excluded" attributes in the above ODD definition. For the same ODD definition, it is possible to enhance the ODD definition by adding additional temporal parameters for attributes that could cause unplanned violation:

```
Excluded transverse plane is [pavements]
Included temporary road structures are [road signage]
Cond_4 Conditional temporary road structures are [refuse collection, road works]
Excluded rainfall is [light rain, medium rain, heavy rain] FOR > 30 seconds
Excluded snowfall is [heavy snow]
Excluded particulates are [mist and fog]
```

***Figure 6**: example of excluded attribute in ODD definition*

By adding the temporal aspect to the attributes, it is possible to convert some “Unplanned” ODD departure conditions into “planned” ODD departure conditions with appropriate ODD attribute value awareness mechanisms. A Distributed ODD attribute Value Awareness (DOVA) (introduced in Khastgir et al., 2022) may be one such mechanism for ODD attribute value awareness, which can be coupled with a broader ODD definition (incorporating the temporal dimension).

2.2.2 ODD attribute violation and ODD departure condition

The temporal nature of an ODD attribute violation emphasizes the difference between the instantaneous violation of an ODD attribute and the CAD system’s decision on “ODD departure condition”. From an NRA perspective, it is essential to understand this nuance as the temporal aspect could enable the CAD system to provide a gradual and graceful MRM execution as compared to a sudden MRM situation which could affect the safety and throughput of the road network. Therefore, any ODD attribute which may trigger an unplanned ODD departure condition, should have a temporal aspect defined to it as a sub-attribute of the ODD attribute.

2.2.3 Planned and unplanned ODD departure conditions

Planned/unplanned ODD departure conditions are related to the capability of the CAD system to prepare itself for a graceful MRM by predicting the imminent violation of an ODD attribute. This is important from a road safety perspective especially when considering a mixed environment where CAD system equipped vehicles and traditional human-driven vehicles co-exist.

In order to better prepare itself for ODD departures (or even better, to avoid them entirely by rerouting or rescheduling trips), the CAD system will benefit from ODD attribute value awareness and might depend on a Distributed ODD attribute Value Awareness configuration to source its ODD attribute information values.

2.2.4 Fixed and variable location ODD departure

Fixed/moving ODD departure conditions suggests to the location at which the ODD departure condition will happen is fixed (and hence could be predictable, not always) and that the CAD system could prepare itself for a graceful MRM by predicting the imminent violation of an ODD attribute. If the CAD system can be aware of all fixed locations in advance, this could be enabled. It is important to highlight that all such fixed locations may or may not be part of the base map of the CAD system.

Most discussions on ODD have completely missed the nuance of fixed/moving ODD departure conditions and its corresponding impact on the system design of the CAD system.

For instances where the CAD system doesn’t have the information about such fixed locations for ODD departure condition, a Distributed ODD attribute Value Awareness configuration could be used to source such information.

2.2.5 Classification of attributes for fixed / unfixed location of ODD departure

It is important to appreciate that a fixed and moving ODD exit condition will be triggered at an ODD attribute level (or a combination of ODD attributes). It is therefore essential to establish these contributing characteristics of each ODD attribute.

In this section, we discuss the classification of various ODD attributes (introduced in Khastgir et al, 2023) into their contribution to a fixed/unfixed location ODD departure. This classification assumes that the CAD system has a base map of the deployment area already loaded onboard.

It is important to reiterate that the planned or unplanned nature of the ODD departure can occur for any of the ODD attributes and could be prevented by enhanced capability of the CAD system. For example, if the CAD system has off-board information of an upcoming section of the road which has roadworks (which is an out of ODD condition for the system), it could prepare itself for a graceful MRM or transition of control.

Table 4: *Quasi static physical attributes of the roadway and its environment (adapted from BSI PAS 1883 scenery attributes)*

ODD Attribute Type	Fixed location	Unfixed location
Locations of road boundaries, intersections, entrance and exit ramps (basic road features)	Y	
Zone boundaries (school zones, traffic management zones, special infrastructure support zones)	Y	
Roadside landmarks to support localisation referencing	Y	
Special-purpose localisation references (buried cables, magnets, etc.)	Y	
Quality of pavement marking visibility (3 or 4 quality classes)	Y	
Load-bearing capacity of roadway or bridge structures	Y	
Road surface damage (potholes, large cracks, ruts)		Y
Game fence locations and condition	Y	
Vegetation obscuring sight angles or visibility of signs or other traffic control devices, at specific locations	Y	
Road geometry constraints such as horizontal and vertical curvatures, grades, lane widths, number of lanes, lane use restrictions…	Y	
Road shoulder conditions on both sides (widths, load-bearing	Y	

ODD Attribute Type	Fixed location	Unfixed location
capacity,…)		
Notifications of locations with occluded visibility (blind intersections or driveways)	Y	

Table 5: *Dynamically changing road surface conditions (part of BSI PAS 1883 scenery attributes)*

ODD Attribute Type	Fixed	Unfixed
Wet pavement surface	Y	
Ice on pavement surface	Y	
Cold pavement surface (potential for ice if wet)	Y	
Road surface friction	Y	
Light to moderate snow/slush accumulation on surface		Y
Heavy snow/slush accumulation on surface		Y
Light to moderate flooding (puddles) on surface		Y
Heavy flooding – potentially impassable to low-profile vehicles		Y

Table 6: *Operational attributes of the roadway (part of BSI PAS 1883 scenery attributes)*

ODD Attribute Type	Fixed	Unfixed
Maintenance vehicles using portions of roadway right of way i.e. carriageway (trimming foliage, ploughing snow, clearing debris,…)		Y
Work zones (road works – construction and rehabilitation)		Y
Incident recovery events (crash scenes, crime scenes, dropped loads, landslides, avalanches…)		Y
Availability of specific C-ITS information services	Y	

ODD Attribute Type	Fixed	Unfixed
Availability of real-time merging guidance or assistance at motorway interchanges or entrance ramps	Y	
Real-time lane-specific speed limit information availability at specific locations.	Y	
Obstacles or debris on road surface (categories such as large discrete objects, distributed smaller objects, continuum of debris such as mud slide or accumulation of sand)		Y
Roadside objects that change their locations over time, such as parked vehicles or trash cans (and could potentially confuse map matching)		Y
Routing advisory information (travel times via different routes)	Y	
Traffic rules and regulations in digital form, updated in real time	Y	

Table 7: *Digital information support for CAD operations (part of BSI PAS 1883 environmental conditions attributes)*

ODD Attribute	Fixed	Unfixed
Variable message sign contents (could be visible and communicated by wireless means)	Y	
Locations where V2I/I2V communications are available now, by specific technology (ITS G5, LTE-V2X, WiFi, 4G or 5G cellular) and uplink and downlink capacities	Y	
Locations where GNSS differential correction signals are available now, by GNSS service (GPS, Galileo, GLONASS)	Y	

ODD Attribute	Fixed	Unfixed
Locations where GNSS coverage is NOT available now, by GNSS service	Y	
Electronic toll collection systems and their associated pricing, especially when these are dynamic based on traffic conditions or time of day	Y	
Locations of incidents that represent traffic impediments or safety hazards (crashes, stopped traffic, objects blocking part of the road) – by lane and milepost or lat /long coordinates		Y
Emergency vehicle locations and direction/speed of travel of each one		Y
Temporarily blocked or closed road locations		Y
Highway shoulder locations occupied by vehicles or debris		Y
Availability of remote human support (remote assistance or remote driving) via wireless communications to aid the CAD system to cope with situations it does not fully understand		Y

Table 8: *Ambient environment attributes (weather, visibility, and electromagnetic environment) (part of BSI PAS 1883 environmental conditions attributes)*

ODD Attribute	Fixed	Unfixed
Wind speed range and direction		Y
Visibility range with rain/snow/sleet/hail in visible light spectrum		Y
Visibility range with rain/snow/sleet/hail in lidar infrared spectrum		Y
Rainfall rate in mm/hr (likely much less useful than visibility range)		Y
Snowfall rate in qualitative ranges (flurries, light, medium, heavy, blizzard and white-out)		Y
Visibility range with other particulate obscurants (smoke, fog, dust, sand, volcanic ash) in visible light spectrum		Y

ODD Attribute	Fixed	Unfixed
Visibility range with other particulate obscurants (smoke, fog, dust, sand, volcanic ash) in lidar infrared spectrum		Y
Predicted significant changes in key weather attributes, including direction and size of change and estimated future time of the change		Y
Qualitative ambient lighting conditions (night/no illumination, night with illumination, dawn/dusk, day/sunny, day/cloudy, day/partly cloudy)		Y
Quantitative ambient lighting conditions (illuminance order of magnitude in lux)		Y
Special challenging lighting conditions (sharp shadows on road, bright sun at low angle)		Y
Electromagnetic interference (where in E-M spectrum, continuous vs. intermittent and level of strength/severity)		Y

Table 9: *Roadway operational attributes (traffic conditions) (part of BSI PAS 1883 dynamic element attributes)*

ODD Attribute	Fixed	Unfixed
Current average traffic speed and density by lane and road section		Y
Current percentage of heavy vehicles in traffic stream, by lane and road section		Y
Special events creating abnormal traffic conditions and their locations (sporting events, concerts, festivals, etc.)	Y	
Locations with high density of pedestrians		Y
Locations with high density of cyclists or users of micro-mobility devices	Y	
Locations with dynamic traffic access changes – time of day or traffic condition dependent access to specific lanes or zones	Y	

2.3 Relationship between information source, information quality and nature of the ODD departure condition

In Kulmala et al. (2023), we have discussed the relationship between the ODD attribute's information source in real-time and the corresponding information quality requirements. In Khastgir et al. (2023), we discussed the information criticality of each ODD attribute. It is also important to highlight that any ODD attribute information which corresponds to the determination of the ODD departure condition is to be considered as safety critical.

From a DOVA perspective, it is important to establish the relationship between attributes contributing to planned and unplanned ODD departure conditions and their information availability time criticality as well as the quality requirements. Taking the example of ODD definition (from section 2.2.1), in order to convert the ODD attribute visibility range in adverse weather conditions into a "planned" ODD departure condition, we need to add a temporal aspect. This temporal aspect might be in the range of seconds, minutes or hours (most likely minutes). Such an extended definition creates an implicit requirement on the system design and the information availability mechanism as the information update interval needs to be shorter than the temporal variation time for the attribute in order to ensure accurate ODD departure condition recognition.

In the above example, this would mean that the CAD system requires information about the current visibility range at an update interval shorter than the time for significant visibility changes (of the order of a minute).

3 Responses of CAD systems and their users to DOVA information

3.1 Introduction

The CAD systems that will be placed into public service will be diverse in capabilities and functionality, aimed at providing different types of service to different transportation markets. Therefore, their needs for DOVA information and their actions in response to receiving that information will be similarly diverse.

Each CAD system will rely on somewhat different technology from other CAD systems, based on the design choices that its developer makes. These choices will be based on the target transportation service to be offered, the target price point and the technical capabilities of the developer. The systems will differ in sensor capabilities and in the capabilities of their software to process sensor outputs to produce assessments of the hazard environment surrounding the host vehicle and predictions of the actions of other road users and of impending ODD constraint violations.

Responses of the CAD systems to DOVA information will also vary depending on when and where they receive the DOVA information and on the level of automation of the CAD system. The earlier the receipt of the DOVA information, the wider the range of alternatives that will be available to the CAD system. If information about likely ODD constraint violations is available prior to trip departure, the driver or fleet operator has the widest possible range of alternatives, but as the time between DOVA information receipt and the actual ODD constraint violation shortens, the available responses diminish significantly. In the limit, when the CAD system only becomes aware that its ODD constraints are about to be violated within a few seconds of the violation, the only available response may be to stop the vehicle.

The type of response will depend on the level of automation of the CAD system. Level 4 CAD systems are capable of executing a minimal risk manoeuvre (MRM) to avoid an ODD constraint violation. If the Level 4 CAD system is fully functional and includes lane changing functionality, the roadway has an unobstructed hard shoulder and the traffic is not too dense to permit the CAD system to reach the shoulder, the MRM would bring the vehicle to a stop on the hard shoulder. However, if the CAD functionality does not include lane changing, or the lane changing capability has been degraded by failure(s), or an unobstructed hard shoulder is not available, or access to the shoulder is blocked by heavy traffic in the adjacent lane, the MRM could involve gradually braking the vehicle to a stop in an active traffic lane, while activating the hazard lights to alert nearby drivers.

Level 3 CAD systems may not be capable of executing an MRM, so their primary response to an impending ODD violation is to warn the person in the driver’s seat (the fallback-ready user) that they need to intervene to resume performance of the dynamic driving task. If the fallback-ready user is indeed not ready and does not respond to the request to intervene in time to avoid the ODD violation, the CAD system would need to request its host vehicle to perform an emergency stop manoeuvre. That would involve a gradual stop in its current lane, with activation of the hazard lights to alert nearby drivers.

Both the MRM and emergency stop manoeuvres would include broadcasting messages to alert the local authorities about the location and nature of these manoeuvres so that they can take appropriate traffic management and emergency response actions. Because these manoeuvres could occur anywhere along a highway, these messages would need to be broadcast over a wide-area wireless communication medium.

It is important to note that production-quality Level 3 or Level 4 CAD systems will be more capable than the Level 2 driving assistance systems that are currently on the market and the prototype Level 3 and 4 systems that are currently under development and testing on public roads. They will have more advanced sensing capabilities, using multiple redundant sensors based on diverse technologies that are not vulnerable to common-mode faults, and indeed all of their safety-critical subsystems (actuators and computers as well as sensors) will be redundant so that system performance will be much more reliable than the current driving assistance systems. This means that the MRM and emergency stop manoeuvres should be rare and isolated events with production CAD systems.

3.2 Timeliness of DOVA information

The primary determinant of the response that a CAD system or its users can take upon receiving DOVA information is the timeliness of that information. The earlier the better, because that means that more attractive response options are available. This is particularly important for static road condition information or information about planned events, which can be known far in advance, even as early as trip departure time.

It is more difficult to provide early information about dynamic ODD attributes that change rapidly in time or space. These could include electromagnetic radiation, which can produce interference with sensors and communication devices with very little advance notice, some weather conditions that can vary rapidly, or traffic incidents that can suddenly create speed changes, impediments or blockages of portions of the road network.

If the CAD system can receive DOVA information prior to trip departure that indicates that part of the intended route for its trip will not satisfy its ODD constraints, multiple options are available to the users and the CAD system:

- Choose a different route that better matches its ODD constraints;
- Delay the trip to a time when its ODD constraints will be better satisfied along the original route;
- Fleet operator may choose to dispatch a different CAD vehicle on this trip, one with ODD constraints that better match the conditions along this route;
- Alert the driver in advance that if they choose this route and departure time, they will need to be prepared to take over the dynamic driving task when they reach the adversely affected location.

Even if the real-time DOVA status information is not available prior to departure, it may still be received well before the CAD vehicle reaches the location where its ODD limitations cannot be satisfied. As soon as the DOVA status information is available, it should be communicated to the fleet operator and/or driver of the vehicle so that they can decide how to respond. These responses could include:

- Divert to an alternative route that is not adversely affected (or is less adversely affected);
- Alert the driver so that they know that in XX minutes or XX km they will need to take over the dynamic driving task, and repeat the alert at several intervals prior to the needed intervention to maximize the likelihood that the driver will indeed intervene as needed;
- In case of a driverless vehicle in fleet operations, the remote assistant can decide the best location to advise the vehicle to perform a shoulder stop MRM or divert to a

parking area if one is available. In this way, the vehicle can be parked in a location where it does not pose any hazard to other road users.

- If the DOVA information indicates that the CAD system will only be able to operate with reduced capabilities (such as limited visibility restricting operating speed), the driver or remote assistant can instruct the CAD system to switch to that reduced functionality mode.

If the ODD condition violation is not known in advance but is imminent (as it would be for real-time condition changes that the CAD system needs to detect using its own sensors, without the benefit of DOVA information), the CAD system response will depend on the level of automation of the system. At Level 3, this would involve a request for driver intervention to take over the dynamic driving task, and at Level 4 this would involve an MRM, as discussed in Section 3.3.

3.3 Minimal Risk Manoeuvre (MRM)

The concept of the minimal risk manoeuvre (MRM) has been under discussion and development within the automated driving system industry for many years. It has long been recognized that there is a need for a countermeasure to minimize traffic safety risks when a CAD system or its host vehicle suffers a serious failure or when it encounters situations that exceed its ODD limitations. ISO TC204 WG14 is developing an international standard for MRM in multiple parts (ISO 23793), the first of which should be published in 2023.

MRM will be a function of all Level 4 CAD systems and it may also be available under some conditions for Level 3 CAD systems but is not a minimum requirement for Level 3 operations. The precise conditions that trigger an MRM response will be unique to each specific CAD system, and cannot be prescribed in a common standard. This is because each CAD system has its own unique limitations based on its complement of sensors and the design and implementation of the software that it uses to combine sensor data with data communicated from the roadside, from other vehicles and from central "cloud" data sources to develop its perception of its driving environment. A CAD system that depends entirely on in-vehicle cameras to detect other vehicles and VRUs will be more sensitive to visibility reductions associated with fog than a system that combines camera data with radar or lidar data or a system that also receives information about the motions of other vehicles and VRUs by communication from roadside devices or the other vehicles. The latter systems will still be able to operate safely under weather conditions that would preclude safe operation by the former system. This diversity of ODD constraints for different CAD systems means that the ODD boundaries for each system will be different, so the potential nightmare scenario of many CAD vehicles trying to perform MRMs at the same time and place is highly improbable.

The MRM is a "last resort" action to be taken when other countermeasures for managing the situation in question (a technical failure of the CAD system or host vehicle or an ODD constraint violation) are not available. The preferred countermeasures for ODD constraint violations are earlier interventions by the driver or remote assistant to change the trip route or timing or to take over the dynamic driving task manually. After those countermeasures have become unavailable, the least risky remaining action is to slow the vehicle to a stop so that it cannot hit something else (another vehicle or a VRU).

ISO 23793 will define a hierarchy of MRM actions that should be taken to minimize the risks to the occupants of the host vehicle and other road users:

(1) The preferred MRM action is to move the host vehicle to the road shoulder or a roadside parking place where it is out of active traffic lanes and to bring it to a safe

stop. However, it needs to be recognized that this action will not always be available for a variety of reasons: (a) the MRM was triggered in a location without a hard shoulder or roadside parking spaces; (b) the shoulder is blocked by debris or other stopped vehicles; (c) the traffic in the lane(s) between the CAD vehicle and the shoulder is too dense to leave adequate space for it to perform the necessary lane change(s); (d) the CAD system does not include the sensors needed for a lane changing capability; (e) the lane changing capability of the CAD system has been impaired because of sensor or actuator failure(s). Under conditions (a), (b) or possibly (c), it is necessary to choose the next best alternative, which is (2):

(2) Move the host vehicle to the reachable lane with the slowest traffic, closest to the shoulder, and gradually slow it to a stop while signalling the slowdown to all nearby road users using its hazard lights and brake lights. In this case, the risk of a secondary crash with traffic overtaking from behind is reduced because that should be slower traffic than in the original lane. It should also be less risky than allowing the host vehicle to continue to drive under conditions outside its ODD constraints.

(3) If the host vehicle is unable to perform a lane change (conditions (d), (e) and possibly (c) above), it should gradually slow to a stop in its current lane while signalling the slowdown to all nearby road users using its hazard lights and brake lights. Although there would be a higher risk of a secondary crash with faster traffic overtaking from behind, this is still less risky than allowing it to continue to drive under conditions outside its ODD constraints.

(4) The last resort among MRM manoeuvres is the basic straight stop, for situations in which the lane sensing or steering actuation systems have been impaired so that it is no longer possible to guarantee that the host vehicle will be able to remain within its original lane, especially when operating on a curved road. This is obviously less desirable than the prior alternatives, but still less risky than allowing the vehicle to continue to drive at full speed under impaired lateral control.

The MRM stopping is not intended to be a hard braking manoeuvre because of the risk of creating a secondary crash with faster traffic approaching from behind. The braking rate should be less than 0.4 g, and if the braking manoeuvre can be initiated far enough from the location where the ODD constraints are violated the braking rate could be substantially lower than this in order to minimize the risks to all road users. In addition to the hazard lamps, the brake lights would also be activated automatically when the brakes are applied to provide visual warnings to all following road users.

The MRM would generate wireless messages indicating the location coordinates of the host vehicle and the severity of the braking that the CAD system is using to stop the vehicle. A short-range wireless broadcast message can alert nearby vehicle drivers and CAD systems about the braking manoeuvre in their immediate vicinity so that they can respond quickly and safely. A long-range wireless broadcast message can alert traffic managers and emergency responders about the stopping vehicle. This is particularly important if the stop is occurring in an active traffic lane rather than on a shoulder, since that will become a traffic impediment and may need emergency responder actions to help clear the blockage.

After the CAD vehicle has completed the MRM, it will be in a standstill state and requires direct human intervention to resume driving. If the vehicle has a human driver onboard, that driver should be able to intervene and resume the dynamic driving task provided that the basic vehicle functionality has not been impaired. If the vehicle does not have a human driver onboard, intervention would be needed by the remote human support staff of its fleet operator. Depending on the level of remote support that is available, this could be remote assistance to provide waypoints for its CAD system to use to drive to an adjacent shoulder stop (if the ODD limitations are not too severe) or remote driving to slowly drive it directly to the adjacent shoulder stop location. If no shoulder is available in the immediate vicinity, physical intervention by an emergency response crew is likely to be needed to remove the vehicle to a place where it can be parked safely.

3.4 Infrastructure-side responses to MRM messages

When the CAD systems execute the MRM they should broadcast messages not only to the other road users in their immediate vicinity but also to the regional traffic managers and emergency responders. These latter messages have not been standardized yet, so they will need some attention by the standards development organizations such as ETSI, ISO and CEN. The relevant information to be included in such messages is:

- Location where vehicle has stopped at conclusion of MRM (preferably including lane as well as longitudinal location along highway)
- Condition that triggered MRM (specific ODD condition violation, specific failure of CAD system or host vehicle hardware or software)
- Braking rate used to achieve MRC.
- Vehicle class
- Number of occupants and their status (in case any may need medical attention).

This information is needed to serve several purposes:

(a) Enable traffic managers to distribute messages to other road users to alert them about the potential traffic impediment from the stopped vehicle, so that they are less likely to be surprised and get into a secondary crash situation, or can change route if this produces a congestion bottleneck;
(b) Alerting emergency responders if they need to dispatch a recovery team to remove the stopped vehicle or provide any needed medical assistance (and what level of recovery team is needed, depending upon whether this is a light-duty or heavy-duty vehicle);
(c) Alerting road network operators if there is a systematic problem at specific locations where too many MRMs are occurring, and helping to identify what corrective actions may be needed to mitigate the problem (road geometry or marking change or additional instrumentation to provide better or earlier information about specific ODD condition problems).

4 Organisational structures and data exchanges

4.1 Data sources, communications, and stakeholders

4.1.1 Roadside data

Historically, most traffic-related data was collected via roadside infrastructure. The most classic example of this is the single/double inductive loop detector in a lane on a stretch of road. Measurements concerned are average traffic speed (time-mean speed), total traffic flow, and occupancy; they are fairly accurate. In addition, they can also be used at traffic signals, where they provide presence detection for queues that build up. However, installing loop detectors is a costly and time-consuming process as it requires a physical procedure to embed it in a road's concrete. Alternatives exist though, with cameras and radars being the most abundant. The logic that governs cameras is fully centred around image processing and detection/identification of (moving) vehicles. Cameras may be working outside the visible spectrum as well, allowing them to operate under night and glare conditions, even in very different weather and visibility conditions. Furthermore, the logic behind modern cameras is able to learn and adapt, something that is inspired by the statistics of machine learning. Aside from cameras, radars are also adopted. Their electromagnetic waves (e.g., laser beams and the like) are sent out as short pulses, which may be reflected by objects in their path, in part reflecting back to the radar. This allows them to perform presence detection. In addition, as they are typically also based on a process that encapsulates measuring the Doppler effect, it is possible for them to estimate the speed of the detected object. To this end, the radar operates using a frequency that is changed by the moving object as the beam is being reflected back to the radar.

Regardless of what detection methodology is used, and what types of measurements are being collected, they are typically compiled in a central data storage. These can be operated by the NRAs themselves, or via intermediary parties that are contracted by them. From that central system, it may then be possible to redistribute them (after quality validations) to other parties, e.g., via a (public) interface.

4.1.2 Vehicular data and communication technologies

Broadly spoken, C-ITS uses several different communication technologies to exchange trusted and secured vehicular data/messages. It offers over-the-air ad-hoc communication networks that enable decentralised direct communication. Typical short-range communication, between devices and/or vehicles in a V2X setup, is based on dedicated short-range communication (DSRC) that takes the form of, e.g., ITS-G5. This is a European standard for vehicular communications based on the IEEE-1609.x and IEEE-802.11p standards, which is being implemented in the C-Roads Platform; it supports data rates between 3 and 27 Mbps in a 10 MHz channel bandwidth, and between 6 and 54 Mbps in a 20 MHz channel bandwidth, and this for a range of up to 1000 m in different environments such as rural, urban, suburban, and highways supporting maximum relative vehicle speeds of 110 km/h. Another method, that by design also supports explicit long-range communications and has no issues with line-of-sight obstructions hindering communications, is based on a cellular infrastructure, using communications technologies such as LTE-V2X, or 5G-V2X.

Note that when considering communication with road-side units (RSUs), a suitable option is to adopt the ITS-G5 communication medium, requiring for example a long stretch of a road network to be equipped with multiple suitable radios and antennas, depending on the curvature and visibility of the road, the expected traffic load, the distance, etc.

Note that, depending on the communication needs of the vehicles, extra restrictions and demands may be imposed on certain technologies. The two main factors that influence this are the amount of information that needs to be (bi-directionally) communicated (translating into the data rate) and the quality and reliability of the connection (translating into latency, error detection, rates of dropped packages, etc.).

Europe's position

The European industry has traditionally had a strong competitive position in the field of intelligent transport systems on a global scale. There is clearly a chicken-egg problem for the implementation of C-ITS. Important questions in the introduction of C-ITS are: where should one invest first? How should one stimulate the business cases? How should interoperability be guaranteed and how should cooperation between private and public partners be developed? To answer these questions, the EC (DG MOVE) set up the platform for the implementation of C-ITS (C-ITS Platform) in November 2014. This platform included stakeholders from private and public organisations, representatives of the vehicle industry, service providers, telecommunications companies, etc. The C-ITS platform delivered a report in January 2016 containing a common vision on the technical and legal aspects. The following topics were also discussed in the report: standardization, cost-benefits, business models, public acceptance, road safety, international cooperation, etc. Recommendations were therefore made for the European Commission and the organisation of the value chain.

The European Commission prepared a delegated act in 2018. It has done this based on the image of the development of sustainable mobility. Sustainable mobility will lead to zero road deaths, less emissions, less congestion, European industry as a world leader and social integration of mobility. This will be achieved through the convergence of C-ITS, connected vehicles, and highly automated vehicles. The EC sees the realization of this path in a time window that extends to 2045.

The delegated act is part of a coordinated approach at European level. The C-ITS platform has developed a common vision. The C-Roads project was started up and is responsible for large-scale implementation. The delegated act should give legal support to this whole process.

The delegated act included the priority services, a roadside infrastructure specification based on ITS-G5 technology and procedures to ensure uniformity and network deployment. Privacy and data security were also included in the act.

Although this delegated act has been approved by the European Commission, there was still opposition to this act. The telecommunication and automotive sectors in particular were opposed: they considered the choice of ITS-G5 too restrictive. They asked that the delegated act be reviewed and made technology neutral. Better technology was already available, and according to them it would be a mistake to impose only ITS-G5. In their opposition to the delegated act, they also referred to China where new C-V2X technology may be rolled out in 2021. As a result, the European act has not been approved by the European Council in mid-2019. Since, ITS-G5 has been deployed in various regions in Europe like in Austria.

4.1.3 Message sets that encapsulate attributes

Depending on the information that needs to be sent/received, a suitable container needs to be used. These typically take the form of the so-called CAM, DENM, MCM, CPM, MAPEM/SPATEM, IVIM, and MCDM V2X message sets.

A full overview is provided in Appendix A.

4.1.4 Relevant stakeholders and message providers

Depending on the different types of information that need to be exchanged, suitable containers and messaging media are used. Directly related to these are the different DOVA attributes that have been defined in WP3.

Provision and consumption of this information is being done through various systems belonging to different stakeholders. The latter typically form a broad range of service providers and contractors in the ecosystem. General weather information can be sourced by a weather service provider, and distributed either directly to other parties, or via an intermediary party such as an NRA. The same holds true for specific traffic-related measurements (e.g., average traffic speeds, network conditions, etc.). However, for the transmission of vehicle-specific information the situation becomes more complex. Here we now have to contend with vehicles themselves, acting as sources and consumers of information. They generate (lots of) data, which needs to be (1) transmitted and (2) used/redistributed. The latter step is in general not done by NRAs or other parties directly, but rather via, e.g., fleet service providers or even the OEMs themselves. In light of DOVA, this will become a recurring theme as the responsibility and liability for that specific information lies with the vehicle and the service provider (they will typically take control based on the available information they amassed themselves). Information flowing the other way, i.e. to the vehicle, can be done in a plethora of ways as explained in Section 4.1.2. Note that also here, there may be the need for an intermediate party that can act as a data verifier/validator before it is transmitted to the vehicles.

It is important to realise here that there is no single best solution per se (i.e. whether to operate fully centralised or decentralised). Understanding where and how the data flows is however key to effective operation of the traffic system as a whole, and the ADS in particular. Multiple alternative ways may exist, and they are mostly dependent on, e.g., what is already present (this relates to costs for rolling out new dedicated infrastructure, organisational systems that may or may not already be in place, etc.) Furthermore, information distribution may be very location specific. An example is a service that is provided by an OEM in one country, but not in another.

Nonetheless, a distributed system such as DOVA provides in general additional value in the data chain as it eliminates the ‘single point of failure’ when relying on a central system to communicate the data. This is also commonly adopted from a risk management perspective as predicated on the lessons learned by the various C-Roads projects. The higher the dependence of an ADS, especially more highly automated systems, on the external information, the greater the impact will be on the ADS operational capabilities and therefore traffic safety in case of lost connection to the information source.

4.1.5 Requirements on data characteristics and information exchange

The general requirements about the quality of data in terms of availability, performance conditions, latency etc. are discussed in Kulmala et al. 2019, Lubrich et al. 2022, and Kulmala et al., 2022. In this section we discuss possible categories of information needs and the characteristics of data related to organisational structures, thereby paying attention to transmitting in-advance information.

It is important to distinguish among the different types of data that are exchanged with the ADS systems on vehicles for different purposes and on the diverse sources of data that are provided to the ADS systems. These have different implications in terms of data quality and update rates and are associated with different roles for NRAs and other stakeholders in the larger road vehicle automation ecosystem.

Much of the work in TM4CAD has been focused on the Distributed ODD attribute Value Awareness (DOVA) concept, but this is only one element in the larger data architecture. DOVA data are used specifically to inform the ADS about the ODD attributes of the roadway segments that the ADS is approaching so that it can know whether its ODD constraints may be violated while using those roadway segments. For example, DOVA data elements represent whether various kinds of support services are **available** along the roadway, but they do **not** include the actual supporting data such as differential corrections for GNSS, remote human support for the ADS, or real-time traffic signal phase and timing messages. These broader (and more extensive) data fall into the larger category of digital support for automated driving.

The ADS systems on the vehicles can serve as both data sources and data receivers. The ADS vehicle sensors can collect data about many attributes of their local driving environment, ranging from traffic conditions to weather and road surface conditions, as well as the condition and actions of the host vehicle. They can broadcast that data to other nearby vehicles, local roadside devices, their fleet managers, or more broadly to cloud-based public or private data repositories including TMCs, These vehicle-sourced data include both DOVA information and the broader types of digital support for automated driving of other ADS-equipped vehicles.

Both DOVA data and the broader digital support data for automated driving may be provided to ADS from a wide variety of sources, including the NRAs (through their TMCs and local roadside devices), as well as direct communication from other vehicles and local direct or area-wide communication from fleet managers, commercial information service providers, or other public agencies such as weather services. The relative importance of these different information sources will vary among countries, among regions within countries (especially urban vs. rural) and by time of day (peak vs. off-peak traffic conditions). The traffic management information ecosystem is thus highly heterogeneous and therefore not susceptible to broad generalizations.

4.1.5.1 Categories of information needs

In the following paragraphs, we consider:

- Emergency information
- Regular traffic management and incident management information
- Mobile sensors by vehicles (cf. probe systems)

Emergency information

When disasters such as big traffic accidents, typhoons or hurricanes, floods, landslides, heavy snow and rain occur, I2V communication can be used to notify the ADS. Here the idea is that by using digital information, the system may need to resort to manual driving in order to evacuate from the area. This emergency information is common with legacy vehicles; a point of attention that remains is how the communication system shares the information with all vehicle types.

In addition, the occupants and/or the drivers may require a detailed explanation of the emergency situation, since they may become (partly) involved in the driving. As such, human factors and human-machine interfaces (HMIs) need to be investigated.

In any case, should this situation arise on the road network, then it stands to reason that traffic management centres will require the reports from (C)AVs (using V2I) of manual driving being conducted after ToC and/or MRM have occurred.

Regular traffic management and incident management information

I2V communication can be used to extend the vehicles' ODD by utilising information from the infrastructure. Hence, in-advance information about unexpected and/or unplanned incidents will help to smooth the transition to adapt to new road traffic situations by extending the ODD. In similar spirit, the same information can help smooth transitions towards ToC and/or MRMs.

In this case, when a situation occurs on the road, the occupants and/or drivers of the vehicles also require a detailed explanation of the situation (via I2V) and the reason why the ADS may lead to a ToC and/or MRM. This latter point is not to be underestimated from a human factors point of view, as it is necessary to avoid the occupants and/or drivers to become chaotic and get into panic.

Finally, should a ToC and/or MRM occur, then it is advantageous to have the ADS report this to the traffic management centre via V2I. The TMC may or may not use this information for daily road traffic management. In any case the reporting provides very important information to improve vehicular technology and extension of ODD attributes.

Mobile sensors by vehicles

Reporting by sensing pavement conditions and the like, and traffic conditions in general, using in-vehicle sensors by V2I has various potential benefits. These are not only for road traffic management, but also for infrastructure maintenance management, and even for planning of new infrastructure.

4.1.5.2 Characteristics of data

An ADS may put certain requirements on the in-advance (or look-ahead) information that is sent as I2V, which ties in with some of the requirements on attributes explained in Kulmala et al. (2022). The benefit of providing such information well in-advance of the change of road traffic situations is that it gives the ADS some allowance time to react and adapt itself. The allowance depends on both the complexity of the information and the operational speed of the ADS.

In the emergency case or the case when an ADS cannot cope with a new road traffic situation, the information is especially necessary for a vehicle's occupants to prepare them for the upcoming situation by explaining the surrounding situation and the reason why the ADS cannot cope.

- **When to transmit to the ADS**
  The timing and location for providing in-advance information depend on the use case at hand. For example, the information regarding the end of a traffic jam or the current weather situation upstream, is directly related to the safety and comfort of the ADS. Such information should therefore be transmitted as soon as a situation changes. The degree of change is different among use cases, and the process of integrating the data from traffic-related and weather-related organisations requires a certain time. On the other hand, the ADS needs information regarding road constructions or road works before the nearest point that allows changing the route. In this case, the information should be provided upstream of the interchange depending on the impact the construction and road works have.
- **Traffic management data**
  Data from a TMC is considered to be objective (with a sense of being instructional) and corroborates evidence about the state of the network, including incidents. The TMC can here possibly integrate local and wide area information from various traffic-related (and possibly weather-related) services, which are then transformed into a

standardised format (cf. C-Roads specifications) should that not already be the case.

- **Fleet operator data**
  Fleet operators are typically different from one another for various brands of ADS. It could therefore be conceived that I2V data which would be transmitted to an ADS from a TMC may need to be modified/adapted by a fleet operator. Performances of ADS are different among brands, and their software might even be different among models and versions. This calls for a strengthening of the relations between, e.g., NRAs (TMCs) and fleet operators; for the former to achieve better results on a global (traffic-wide) level, and for the latter to achieve better performance for their ADS. A crucial step in this direction is the definition of and agreement on the types of data that should be exchanged and their related attributes; examples of this are already given in Kulmala et al. (2022).

- **Probe vehicle data**
  Well-known information obtained from probe vehicles are travel times, congestion delays, driving behaviour, and perceived weather and road surface conditions. In addition to providing a TMC with information that is location specific, probe data can also encompass route- and/or section-wide information. The systems utilising V2I communications for collecting vehicle-related and/or sensor-related data have the potential to improve road traffic management. While the idea is not new, the reason for the slow popularisation is the lack of direct benefits to the vehicles. Nevertheless, the developments of vehicular technologies and the expected future penetration of ADS indicate that communication between vehicles and infrastructure becomes easier. Here, the first step is to recognise the merits of probe data for TMCs (and more specifically the ADS data).

- **Expected new contributions to road traffic management**
  For heavy-duty vehicles, the vehicle weight information can be transmitted via V2I to a TMC, which can help to mitigate damage to road surfaces and infrastructure. This is especially effective, considering that for now most of these measurements are done via, e.g., weigh-in-motion (WIM) systems that are scattered over the road network.

  Another possible benefit from an ADS to a TMC is that the former can transmit recorded images from the forward cameras, especially in case of traffic accidents, in order to help grasp the outline of the accident before action is taken. A big barrier here however is the issue of privacy, e.g., being GDPR-compliant in Europe, which may limit the use of these techniques.

4.2 Possible organisational structures

In this section we build further upon the information needs expressed in Section 4.1 by providing examples of possible organisational structures that embody and explain the relations among the various actors, such as ADSs, vehicle OEMs, NRAs, other service providers, etc. It is important to understand that for any such structure considered, there is a need to identify the required capabilities from the point of view of the ADSs, the OEMs, and the NRAs. This holds even more so true for the intermediate 'nodes' that make up these structures. An additional concern is that data sent by one system/actor is being interpreted by another one, and that interpretation may or may not be the same as originally intended; hence, it is necessary to understand the consequences of such differences. In a more formal setting, this deals with data liability and accuracy: how will the systems/actors cope with incorrect data, and what is exactly meant by data being deemed incorrect?

In the following paragraphs, we first highlight some of the relevant stakeholders in the ecosystem, followed by insights into organisational structures that are more oriented towards centralisation as well as decentralisation, finally elaborating on the responsibilities of NRAs (infrastructure side) and OEMs and automation technology developers (vehicle side).

4.2.1 Stakeholder roles in the ecosystem

Generally speaking, the ecosystem can be decomposed into various (groups of) stakeholders and roles. An example is given by the Data for Road Safety Multi Party Agreement (Data for Road Safety, 2020), where we have:

- Data source
- Data aggregator
- Data clearer
- National access point
- Creator
- Service provider

We can envisage that the following extra parties are relevant in the context of DOVA:

- Vehicle OEMs
- NRAs
- Tier-1 technology providers
- Full-stack vehicle automation developers
- EU/EC
- Standardisation bodies
- Member States

The concrete content of the roles they each take upon may be specific to the use case that is being considered; we refer to Section 5 for a more detailed overview of the stated actors and their relations.

4.2.2 Centralisation versus decentralisation

The key difference between more centralised versus more decentralised organisational structures is that in the former information is generally aggregated at unique nodes in the organisational network which take on more heavy roles, whereas in the latter there is a more distributed responsibility for managing the information.

To concisely highlight some of the aspects related to this, assume an example with the following actors involved: vehicles, their respective OEMs, automation technology providers and fleet operators, an NRA in this case represented by a TMC, and a third-party service provider (e.g., weather information). Let us then take on two extreme views on how cooperation between actors may occur.

- In a centralised organisational structure the TMC would like to:
    - gather all the relevant information (that is, higher-level data from all ADS (not per se the millisecond-by-millisecond data),
    - aggregate and validate/clear third-party information,
    - validate its own traffic state-related information,
    - and disseminate this to the vehicle OEMs/technology developers/fleet operators and ultimately their vehicles' ADS.

- In a more decentralised environment, this tight link between the TMC and other actors is relinquished, leading to more loose couplings among the actors:
    - the TMC sees itself more as a content provider for the information that it represents itself, e.g., traffic state-related information,
    - the vehicles' ADS gather data directly using their sensors and communication devices.
    - the vehicle OEMs/technology developers/fleet operators may gather additional relevant data for their ADS by incorporating information from the TMC as well as the third-service providers.

It could be argued that the former leads more to an instructional role of the TMC whereby it extends the wish to be able to have more direct 'control' of the vehicles. Keep in mind though that this will quasi-never be the case, leading to TMCs solely providing (stringent) advice to an ADS. There are various mechanisms possible to achieve this, i.e. either by providing direct advice to a single vehicle or a group of vehicles, or by altering the conditions of the managed operating environment and modifying the ODD attribute values (which can possibly be encoded in the rules of the road). And while an ADS may be under some pressure to comply with a given advice, the responsibility for directly executing this still lies with the ADS and not the TMC.

It is not per se clear cut as to what is the best approach for cooperation among the various actors. Rather, each perspective has its own set of advantages and disadvantages. A straightforward aspect that needs to be taken into account is the issue of trust: an ADS (and vehicle OEMs/technology providers//fleet operators in general) would not easily trust data that comes from external sources and enters their systems. This by itself puts limitations on what is possible regarding data exchanges. A solution here may be to use an intermediate party that would act as a data clearing house to safeguard and validate the quality of data that is to be sent (this works in all directions among all parties). Different levels of data exist (e.g., raw data, enriched data, aggregated data, etc.), and what type is shared among the different nodes in the organisational structure depends greatly on what trust is given to them. An ADS may require to have raw data and do the validation by itself, whereas an NRA/TMC may benefit more from some form of enriched/aggregated data (albeit the latter would typically be expressed in a standard format). As such, it is up to the ADS (or its operating entity) to collect all the relevant information, assuming that all information is always available but the ADS will perform filtering by itself. For the latter we could fall back on the attributes that were defined in Kulmala et al. (2022) together with the requirements imposed on them, e.g., regarding timeliness, etc.

For NRAs/TMCs the benefits are clear-cut, in that "digital road operators" become more ODD-aware: as they monitor the ODD attributes in real-time, they can have better performing traffic management schemes that are being triggered based on (ADS-varying) critical ODD attribute values. Incorporating these, they can have a wider view of the network than their own fixed-location-based sensors can give, and they can predict these values and foresee critical hotspots and even publish the information through (digital/in-vehicle) signage.

In any case, the issue of trust needs to be addressed, as it lies at the core of the DOVA framework, in that the entire goal of having extra information provided to an ADS serves to extend its information horizon thereby leading to improved performance and safety.

One option, explained in the next chapter, for digital road operator to provide critical C-ITS information for partly automated vehicles in Europe are the C-Roads Platform's defined Automated Vehicle Guidance (AVG) services. The services are not part of regulation neither do they guarantee a safe operation; the aim is to provide additional information for the vehicle's decision-making process. The two C-Roads service specifications include SAE automation level guidance and platoon support information (see section 1.5). The former provides road operator information and guidance about suitability of partly automated vehicle on certain road or lane segments and the latter service provides guidance and information on the suitability of platooning on specific road section

4.2.3 A note about the responsibilities of NRAs and OEMs

Traffic managers, or more broadly defined traffic management centres (TMCs) and their traffic management systems (TMSs), are typically collecting information both on their own as well as using information from other service providers. Examples of this are the plethora of cameras, radars, and inductive loop detectors installed along various sections of different roads. In principle, these suffice to get a global picture of the macroscopic state of a (part of the) road network. This may be enough for many types of operational traffic management systems. However, with the advent and rise of more automated vehicle systems, and the close linkage between ODD and ISAD, new – extra – sources of data and information are becoming available. The primes of these are already regulated under the European Commission's **safety-related traffic information (SRTI) Directive**. Despite this, progress and further insights lead to more types of information, sometimes even becoming very specific. In addition to, e.g., vehicles broadcasting their real-time locations, there is also the possible access to information on a more vehicle-operational level, such as accelerations, feedback from the ECU (think of road slippage, detection of wet conditions, windshield wipers, etc.), and so on and so forth.

That said, it may not currently be an explicit need of TMCs to have access to the latter kind of information if the infrastructure-based monitoring systems provide sufficient data of the prevailing conditions. Nevertheless, progress is also being made on the front of TMSs. Even though the adopted algorithms and control techniques are not using such detailed information, we could envision that it would be very helpful to them. As such, while it is not a direct requirement, there may be a strong positive incentive for TMCs/TMSs to obtain access to vehicle-specific information. It became clear at the TM4CAD workshops that especially the network coverage and location accuracy would improve drastically with vehicle data covering the whole road length while the infrastructure sensors at best cover sections with 500 m to 100+ km interdistance or some hot sections like tunnels. This would allow them to merge those new inputs in their own models with their own data. Data harmonisation, assigning belief to data (in a Bayesian context, e.g., for training algorithms; in order to distinguish data that is realistic, applicable, and to be trusted from data that maybe invalid, erroneous, or irrelevant), and extra input for validation are key in this respect.

Therefore, provisioning of detailed data streams to the TMCs/TMSs may become much wanted. The most relevant types of information that come straightforward to mind are related to dynamic inputs, which have also been elaborated in the previous section. Note that this is not just to accommodate people in an operation control room setting, needing data to act upon directly, but also to support any – more automated – system for traffic management that benefits from a wide range of data, past, present, and future predicted, in order to take decisions.

Of course, it makes sense that there should be a mutual exchange between the information collected/provided by road operators/TMCs/TMSs and OEMs, leading to shared benefits. In this case, it may become a requirement to have a suitable information broker (that may even function as a data clearing house if needed).

With regard to the distributed ODD attribute value awareness (DOVA framework, the road operators and traffic management centres need to be involved in providing their views and inputs to the development of the framework. A good example here is the need to involve the road operators and traffic managers in the development of the treatment of the edge cases (i.e. in which the vehicle would end up outside its ODD and hence may need to relinquish control back to the driver or taking prompt action if that is not possible) including the carrying out of the minimal risk manoeuvres (MRM) in a way that will not endanger the safe and efficient road network operation.

In the deployment of the framework, the road operators are responsible for deployment of the framework in the road infrastructure (data acquisition infrastructure, short-range communication infrastructure, digital twins, etc.) and also in the contracts of the road and winter maintenance operators who are also providing real-time data on the maintenance actions and their location to the Avs via the OEMs including the stakeholders managing the AV fleets. The DOVA framework deployment also applies similarly to the traffic management centres and the stakeholders responsible for some tasks via specific contracts.

When the DOVA framework is in daily operation, the traffic management centres and the maintenance contractors use the DOVA in their practical activities. Both road operators and traffic management centres as well as the contractors working for them are responsible for monitoring the use of the DOVA and see to it that the components of the DOVA framework under their own responsibility are operating as intended and agreed.

CAD vehicles are expected to function independently from any other system, to be self-sufficient. This means that CAD vehicles can drive safely and smoothly on the basis of their own information channels such as onboard lidars or cameras, and they are capable to determine their own degree of automation based on the match between the sensed environment and the ODD, sending a timely signal to the occupant to request a takeover, or performing a minimal risk manoeuvre.

Redundancy of information and backup procedures are required to reduce risks in this standalone operational mode. With respect to this redundancy, infrastructure and dynamic traffic management can play a major role of importance. The interplay between road operators and OEMs is paramount here: a road operator is supposedly able to detect/relay the information of, e.g., upstream events that are currently not accessible/knowable/detectable to/by a specific vehicle. In other words, information that is either outside of the range of the vehicle's own sensors or information which nature is such that it cannot be detected by the vehicle. This way, the contextual awareness of a CAD vehicle can be extended by complementing it with extra information stemming from the road operator. This provides a tight link with distributed ODD attribute value awareness and management.

In any case, all behaviour stemming from automated driving systems is supposed to be a consequence of the traffic rules, the (distributed) ODD, and the technical capabilities of the specific CAD vehicle.

Roles can be taken on by different actors/stakeholders, implying that not everything relating to traffic management and road operation needs to be done by an NRA, as it can be dealt with by other parties. Hence, it is not strictly necessary for an NRA to tackle all the difficulties and information exchanges themselves.

Certain boundary cases may still require further attention as to who takes on which responsibility. For example, a case where an ADS can perform during 90 % of a route, can lead to the requirement that the driver needs to intervene for the remaining 10 %, or it could lead to a choice that is taken on earlier (i.e. at the start of the trip) to choose another route (which may be longer, more unfamiliar, etc.) for which the driver may or may not have to take a decision for approval.

5 Use cases

Previous chapters and earlier TM4CAD deliverables have defined a set of basic principles which NRAs can apply to any use case. A use case description usually consists of the same number of elements, which include a description of the ADS, the scene or situations the ADS is in, a description of the expected behaviour of the system, a list of actors and their role in the use case, and the storyline of the use case based on a sequence of situations, events and actions. Use cases typically describe functional constraints and dependencies that are requirements.

The most fundamental principle with regards to the operation of ADS and TM4CAD concepts is that (only) the ADS decides if it is capable to handle the current local conditions based on its situational awareness. This has three implications for NRAs:

1. Traffic management systems will not actively manage the tactical or operational decision making of ADS, i.e. activate and de-activate automation, instead its added value to ADS and thereby traffic safety lies in improving the situational awareness of ADS and providing strategic guidance.

2. The driving rules and expected driving behaviour must be defined in regulations such as the Vehicle General Safety Regulation and UN Regulations. ADS developers will define the ODD of their systems in line with the boundaries as defined by these regulations.

3. Information beyond the line-of-sight of vehicle sensors is relevant for timely anticipation of the downstream conditions. This is where NRAs support ADS the most today, by providing information in advance. Currently there is no indication that ADS will comply with tactical and/or strategic guidance provided by e.g. a TMC. It could decide to follow strategic guidance regarding for example identifying the fastest route to take to reach a particular destination.

With these implications in mind we recommend NRAs to actively participate in and contribute to the development of the regulatory framework for ADS such as (European Union, 2022). It is important that the concerns and experiences of road operators are considered upfront and that ADS technology developers and road operators jointly interpret the regulations to assess if known edge cases and known safety critical situations in day-to-day operations are sufficiently covered.

Moreover, as first mentioned in Chapter 1, regulations can be used to exclude ADS operations from certain locations, situations and/or location-situations. For example, ADS may not be allowed to operate at tunnel locations, in fog situations or at tunnel locations in case of foggy conditions. A better approach in our opinion would be to let the ADS decide if it can operate under the local conditions and instead define a framework for 'expected drivership'. Such a framework would specify the minimum driving skills and acceptable driving behaviour of ADS in a particular situation. In other words, it describes the rules of the roads an ADS must adhere to as well as the driving behaviour the ADS is supposed to reveal. This is further discussed in the WP5-report of TM4CAD (Maerivoet et al., 2022).

When participating to a constructive dialogue between NRAs and ADS technology developers it is important to establish a common vision and ambition. For example, in the short term the interested parties can express to work together on objectives such as avoiding unsafe driving of ADS and any disorder of traffic flow. For the medium term the interested parties can agree to collaborate on ADS overcoming limitations associated with Distributed ODD attribute Value Awareness. For the longer term perspective, the involved parties can aim for their mutual interests in the better management of traffic volumes and traffic flow dynamics, enabled by vehicle automation in case the penetration rate of ADS becomes sufficiently high.

5.1 Decision-making process for NRA role

Current ADS immaturity causes a lot of uncertainty for road authorities as they cannot decide with confidence what is the best way to anticipate ADS development and deployment to preserve operational safety and efficiency on their road network. Typically, the actual competencies of ADS in the operating environment are not entirely known and ADS capabilities are regularly overestimated or underestimated based on assumptions that are derived from the scarce information that is publicly available. At the same time, many different situations can occur on open roads and in variable traffic and weather conditions, in particular when these roads are dynamically managed by the road operator (e.g. lane, speed and tunnel management). It is natural that NRAs are concerned about the introduction of ADS that execute the complete dynamic driving task. The most constructive and perhaps only way forward is to create a dialogue between road authorities, automation system developers and regulators. Building upon the rationale of the previous chapters, the flow diagram below intends to support NRAs in this conversation and to break down the use case assessment in smaller elements.

As was explained in TM4CAD deliverable 2.1 (Khastgir et al., 2022) and summarised in chapters 1 and 3 of this report, the ADS decides if it can operate in the local conditions based on the situational awareness it has. Off-board sensors can improve the situational awareness and provide information in advance, which may increase the ability of the ADS to manage these local conditions. For example, the ADS may hand over the dynamic driving task to the vehicle driver earlier, the ADS may handle the complexity and operate in the local conditions itself and/or the ADS may improve the driving performance and driving comfort. *This logic applies to all local conditions therefore the scenario flow for all use cases is very similar.*

For any given use case (i.e. the combination of a local condition of concern and an ADS), the first question to ask is (1) whether the local condition is within the ADS sensor range so that the ADS can respond to the condition in time. For example, a downstream traffic jam or weather condition is typically not within the sensor range of ADS. If the local condition is within the ADS sensor range, the next question (2) to ask is whether the ADS can operate in the local condition or not. In other words, is the local condition within the Operational Design Domain of the ADS and when the ADS detects it, is the ADS able to handle the complexity of the situation? If the answer is positive, the third question (3) to consider is whether the ADS can operate the vehicle to conform with expected or desired driving behaviour. Perhaps the ADS decides it can operate in the local conditions, but the resulting driving performance is poor, for example a (too) low driving speed and/or a (too) long response time. Clearly, the assessment of driving performance requires a benchmark to determine what is ‘correct’ and acceptable behaviour as stated above. If all three questions are answered ‘YES’, the ADS can operate the vehicle also from the point of view of the NRA.

However, the answer ‘NO’ to any of the first three questions leads to another flow which is more NRA-oriented. The first consideration (5) is whether off-board sensors can provide information about the local condition of concern. If so, it is worthwhile to assess (6) if the ADS will actually benefit from off-board information in the particular local condition. If the situational awareness and/or decision making modules of ADS are not able to process and act on the information or it will not improve the driving behaviour of the ADS, there is no point in making it available. Though, when both questions are answered positively and no (non-NRA) source exists that can provide the information, the NRA has to weigh (7) if the frequency of the local condition occurring and the impact of the ADS response to the local condition justify and require investment by the NRA. This is a policy and planning decision.

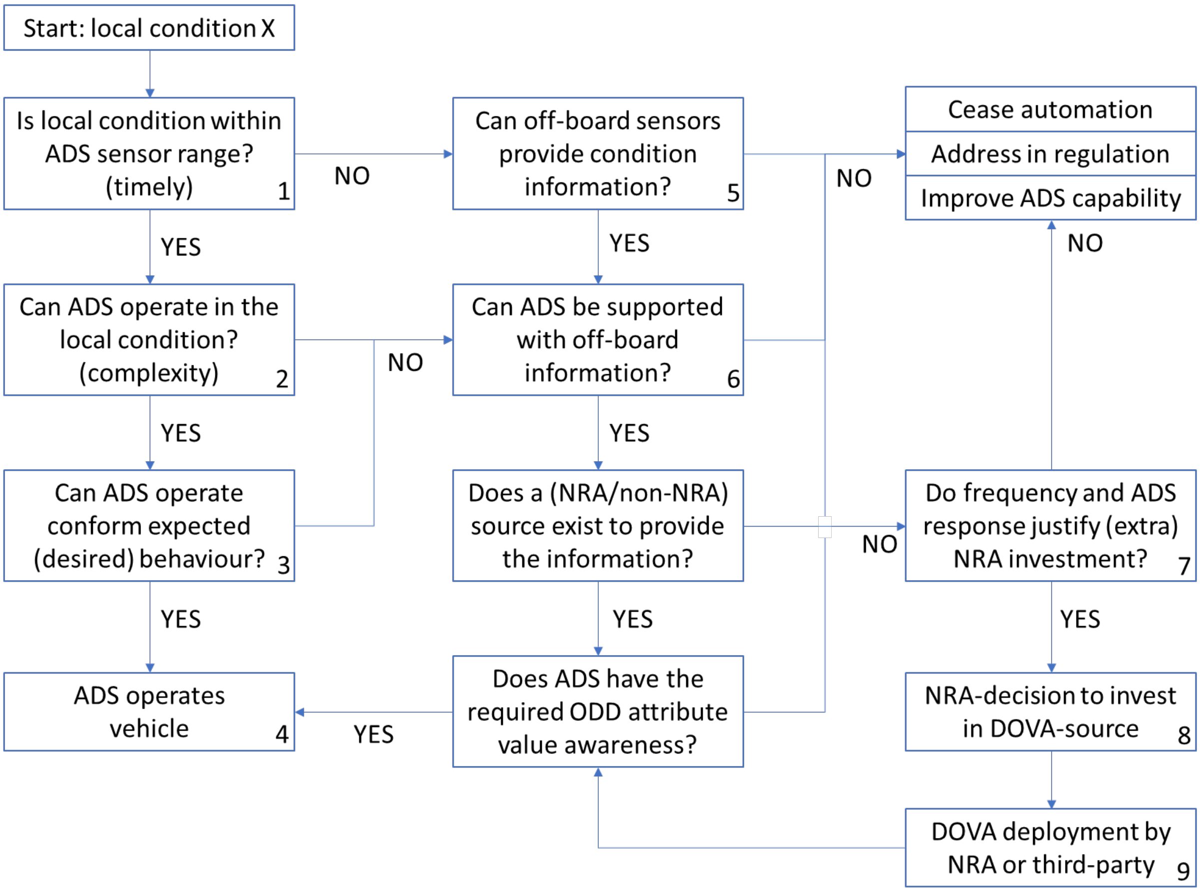

***Figure 7**: decision-making process for NRA role*

For this deliberation it is important that NRAs are well informed about ADS competencies, capabilities and driving behaviour, as well as differences between high-end and low-end vehicles, current and future vehicle capabilities, and different brands of vehicles. With regards to the driving behaviour of ADS more precise information about the minimal risk manoeuvre is needed, in particular what the minimal risk condition (MRC) is. The MRC is entirely situation dependent and represents the lowest risk action that can be taken under the current combination of vehicle and ADS failures, ambient conditions, current traffic density surrounding the ADS vehicle, whether a hard shoulder exists nearby and whether that shoulder is open or obstructed by other vehicle(s) or debris. From the NRA and traffic safety viewpoint it matters greatly if minimal risk condition in the case of ALKS means a full stop in the driving lane, or if it means to stop the vehicle on the hard shoulder or to continue driving the vehicle at 60 km/h. Finally, even when the frequency of occurrence and impact of the ADS response to the local condition justify exploring counter measures of some sort, it does not necessarily mean that NRAs are required to act. For some local conditions the sensible outcome may be that the ADS is inadequate and the logical solution is appeal to the vehicle manufacturer to improve the ADS capability. In case the questions 5-7 are answered 'YES' it means that the outcome is in favour of (8) a Distributed ODD attribute Value Awareness solution. As described in chapter 4 there are several governance options for NRAs to move forward at this point, ranging from the NRA doing the information collection, processing and distribution by the NRA to mandating a (trusted) third-party to fulfil this job. Either way, when the DOVA solution is present (9) and information about the local condition is available to the ADS, the ADS can operate the vehicle (3).

Lastly, the answer 'NO' to any of the NRA-related questions (5-7) leads to the outcome that the ADS must cease automation in the case of this particular local condition. This means that the necessary situation awareness cannot be obtained by ADS due to the absence of information, ADS are not designed to operate in the local condition or ADS adhere to the expected driving behaviour standards. Depending on the observations made throughout the flow diagram, it may be appropriate to address the local condition in ADS regulation. For example because the situation is a special circumstance, safety critical, occurs frequently and/or has a high probability of causing undesirable behaviour. As a consequence and as also stated above, in some cases there is a task for vehicle manufacturers to improve the capability of ADS.

5.2 Actor landscape and introduction to use cases

The following sections provide use case descriptions for four different situations: adverse weather conditions, road works, traffic jams and tunnels. For each use case multiple scenarios are provided, each describing the actions of the actors involved. Actors are roles and not to be confused by stakeholders; an actor role can be fulfilled by any stakeholder (e.g. NRA), while one stakeholder can take on multiple roles.

Figure 8 below shows an actor landscape and the actor relationships in a schematic and simplified way. It can be summarised as follows: the role of the ADS is to perform the dynamic driving task and uses on-board and off-board sensors to create situational awareness. It can request the vehicle driver to take over the driving task (a) while the vehicle driver can activate and deactivate the ADS (a). The primary sources of off-board information are assumed to be the road operator / traffic manager (c) and the information service provider (b). Road operators / traffic managers can have different communication channels to publish information ranging from roadside signalling equipment to digital cloud-based solutions. They can provide information to vehicle drivers and ADS directly (c/d) and/or via information service providers (e). An information service provider can be a third-party information broker or vehicle fleet operator that facilitates the exchange of information between road authorities and fleets of vehicles, which are operated by either vehicle drivers or ADS. Information service providers can aggregate information coming from other specialist actors, such as roadworks contractors (g) and meteorological data providers (f). Roadworks contractors manage the road works site and can provide real-time information about of the location and topology of the site. Its contract with the road operator (h) specifies the obligatory actions that it needs to carry out. Meteorological data providers can provide real-time information about the location, type and severity of weather conditions (f). Another source of information for information service providers can be ADS (b), which can sense local conditions with on-board sensors and collect and provide probe vehicle data. Similarly, the road operator / traffic manager can benefit from this probe vehicle information once it is aggregated to obtain a better understanding of the local conditions on the road network (e). In fact, this information can enable the road operator / traffic manager to provide local condition information to other actors. Naturally, also other information flows likely exist such as information service providers providing information directly to the drivers via e.g. nomadic devices or meteorological data providers to road operators or traffic managers. Figure 8 focuses on the information flows related to DOVA.

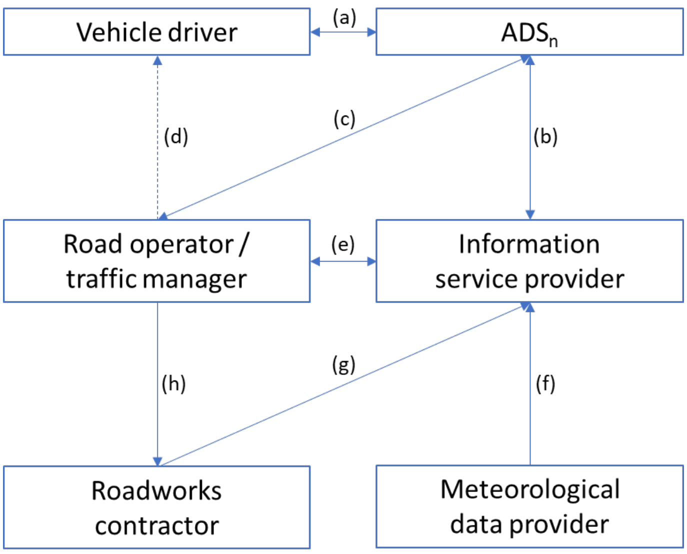

***Figure 8**: actor landscape of DOVA use cases*

Due to the structured way the use case scenarios are described their commonality becomes visible. In each scenario an ADS receives in-advance information about a local condition further down the road. As the ADS is informed about the local condition and the (detailed) characteristics of the condition, the ADS assesses the situation, performs the dynamic driving task as long as possible, avoids the local condition or transfers the dynamic driving task to the vehicle driver. This is illustrated in Figure 9.

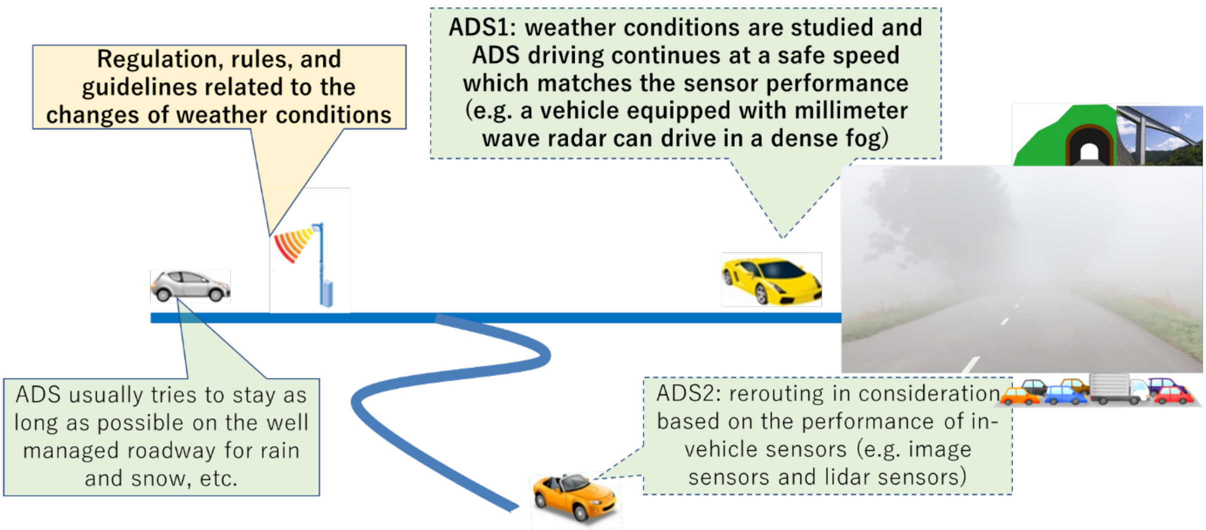

***Figure 9**: illustration possible ADS handling in-advance information (courtesy of H. Kawashima)*

5.3 Adverse weather condition use case description

Use case introduction	
Summary	A vehicle operated by an ADS approaches an adverse weather condition.
Background	It is assumed that without an intervention the ADS will approach and detect the adverse weather condition (e.g. fog, heavy rain, strong wind or ice on the road), observe that the local conditions do not match the ODD of the system, and transfer the dynamic driving task to the driver in case of a Level 3 ADS. In case of a Level 4 system the ADS will make a minimal risk manoeuvre.
Objective	Timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.
Desired behaviour	The ADS can travel through the adverse weather condition as normal, or it can transfer the control of the vehicle to the driver in a safe and timely manner. In case of the latter, the driver operates the vehicle through the adverse weather condition.
Expected benefits	With less ODD fragmentation, the ADS manufacturer can provide better continuity of service and thereby improve its competitiveness via improved attractivity to the vehicle buyer. In other instances, the ADS manufacturer can provide a smoother service when the dynamic driving task needs to be transferred to the vehicle driver. The driver can experience better continuity of services, with fewer interventions caused by transfer of control requests. In case the dynamic driving task does need to be transferred to the vehicle driver, the driver can experience a more user-friendly and informative service compared to the case with unexpected takeover requests. The road operator/ traffic manager experiences fewer minimal risk manoeuvres by ADS and fewer accidents in adverse weather conditions due to safer driving behaviour of ADS.
Situation	2-lane motorway with free-flow traffic at twelve noon and adverse weather conditions 2 km downstream of the current position of the ADS-operated vehicle.
Actors and relations	ADS: performs the dynamic driving task and uses on-board and off-board sensors to create situational awareness. Upon detection of the

Note: actors are roles and not to be confused by stakeholders; an actor role can be fulfilled by any stakeholder (e.g. NRA), one stakeholder can have multiple roles.	adverse weather condition the ADS assesses if it is capable to operate in the local conditions. If not, the system will request the vehicle driver to take over the dynamic driving task. Vehicle driver: is not performing the dynamic driving task. In case of a L3 system the driver must be available to resume the driving task when requested, in case of a L4 system the driver does not have to be available. The driver resumes the dynamic driving task if the ADS requests them to do so and if the driver is capable to do so. Road operator/traffic manager: operates the motorway by means of roadside systems and TMC services. It publishes information about the adverse weather condition via different communication channels to service providers, vehicle systems and vehicle drivers. Meteorological data provider: provides real time information about the location, type and severity of weather conditions. Information service provider: third-party information broker or vehicle fleet operator that facilitates the exchange of information between road authorities and fleet of vehicles which are operated by either vehicle drivers or ADS.
Use case scenario	Scenario 1: allow timely handover The road operator or traffic manager maintains and publishes a real-time overview of weather conditions on the road network based on information provided by a meteorological data provider. The information service provider ensures that the information is available to ADS. Upstream of the area where the adverse weather condition is present the ADS receives information about the imminent adverse weather condition. If the ADS is not designed to operate in the particular adverse weather condition, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resume the dynamic driving task. An alternate outcome for this scenario is that the ADS plans an alternative route and avoids the adverse weather condition. Scenario 2: guided through the adverse weather condition The road operator or traffic manager maintains and publishes detailed real-time information about weather conditions on the road network based on data provided by a meteorological data provider. In addition, the road operator or traffic manager activates road management (e.g. lane closure) and/or traffic calming measures (e.g. reduced speed), which are also published. An information service provider ensures that the information is available to ADS. Upstream of the area where the adverse weather condition is present the ADS receives information about the imminent adverse

	weather condition and the traffic management measures that are in place. The ADS assesses whether it can operate in the local conditions ahead with the information it received. If yes, it continues driving possibly with adapted driving behaviour, if not it requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task.
Functional constraints / dependencies	Road network related weather condition information must be collected and frequently updated. This is a responsibility of the road operator who is likely to outsource data capture and update tasks to a meteorological institute. The weather condition information must be available digitally with sufficient level of accuracy and timely updates in case of changes. It should have a sufficient level of detail in terms of condition classification and the intensity estimation. In addition, it should be predictive to a degree which is proportional to the level of granularity. Information can be delivered to the ADS in several ways. One way is to build upon C-ITS deployment practices as documented by C-Roads and using C-ITS messages DENM and IVIM. Aside direct short-range communication, information may flow through National Access Points and other backends of a third-party information broker and/or vehicle fleet operator. Alternatively, there may be a place and role for a Digital Twin, which is further elaborated by the CEDR 2020 DiREC project.

5.4 Road works use case description

Use case introduction	
Summary	A vehicle operated by an ADS approaches a roadwork zone.
Background	It is assumed that without an intervention the ADS will approach and detect the roadwork zones, observe that the local conditions do not match the ODD of the system, and transfer the dynamic driving task to the driver in case of a Level 3 ADS. In case of a Level 4 system the ADS will make a minimal risk manoeuvre. .
Objective	Timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.
Desired behaviour	The ADS can travel through the roadwork zone as normal, or it can transfer the control of the vehicle to the driver in a safe and timely

	manner. In case of the latter, the driver operates the vehicle through the roadwork zone.
Expected benefits	With less ODD fragmentation, the ADS developer can provide better continuity of service and thereby improve its competitiveness via improved attractivity to the vehicle buyer. In other instances, the ADS developer can provide a smoother service when the dynamic driving task needs to be transferred to the vehicle driver. The driver can experience better continuity of services, without fewer interventions caused by transfer of control requests. In case the dynamic driving task does need to be transferred to the vehicle driver, the driver can experience a more user-friendly and informative service compared to the case with unexpected takeover requests. The road operator/traffic manager experiences fewer minimal risk manoeuvres by ADS and fewer accidents in roadwork zones due to safer driving behaviour of ADS.
Use case description	
Situation	2-lane motorway with hard shoulder, with a roadwork zone on the left driving lane. Traffic is diverted to two narrower driving lanes using the right lane and the hard shoulder. Maximum driving speed in the roadwork zone is 70 kmh.
Actors and relations Note: actors are roles and not to be confused by stakeholders; an actor role can be fulfilled by any stakeholder (e.g. NRA), one stakeholder can have multiple roles.	ADS: performs the dynamic driving task and uses on-board and off-board sensors to create situational awareness. Upon detection of the roadwork zone the ADS assesses if it is capable to operate in the local conditions. If not, the system will request the vehicle driver to take over the dynamic driving task. Vehicle driver: is not performing the dynamic driving task. In case of a L3 system the driver must be available to resume the driving task when requested, in case of a L4 system the driver does not have to be available. The driver resumes the dynamic driving task if the ADS requests them to do so and if the driver is capable to do so. Road operator/traffic manager: operates the motorway by means of roadside systems and TMC services. It publishes information about the roadwork zone via different communication channels to information service providers, vehicle systems and vehicle drivers. Roadworks contractor: manages the road works site including the local traffic management via cones, signs and road markings. It can also provide real time information about the location and topology of

	the road works site. Its contract with the road operator specifies the obligatory actions that it needs to carry out. Information service provider: third-party information broker or vehicle fleet operator that facilitates the exchange of information between road operators and fleet of vehicles which are operated by either vehicle drivers or ADS.
Use case scenario	Scenario 1: allow timely handover The road operator or traffic manager maintains and publishes an overview of the location of roadwork zones based on information provided by roadworks contractors. An information service provider ensures that the information is available to ADS. Upstream of the roadwork zone the ADS receives information about the presence of the roadwork zone. As the ADS is not designed to operate in roadwork zones, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resume the dynamic driving task. An alternate outcome for this scenario is that the ADS plans an alternative route and avoids the roadwork zone. Scenario 2: interpret the roadwork zone The road authority maintains and publishes *descriptive* information about roadwork zones such as precise location, speed limit, lane permissions and restrictions, etc. based on information provided by roadworks contractors. An information service provider ensures that the information is available to ADS. Upstream of the roadwork zone the ADS receives the descriptive information of the roadwork zone. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving possibly with adapted driving behaviour, if not it requests the vehicle driver to take over de dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. Scenario 3: guided through the roadwork zone The road operator maintains and publishes *detailed* information about roadwork zones such as the road and lane topology, lane permissions and restrictions, presence of objects and barriers, recommended trajectory, etc. based on information provided by roadworks contractors or probe vehicles that already passed the roadwork zone. An information service provider ensures that the information is available to ADS. Upstream of the roadwork zone the ADS receives the detailed information about the roadwork zone. The ADS assesses if it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving possibly with adapted driving behaviour, if not it requests the vehicle driver to

	take over de dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task.
Functional constraints / dependencies	The information about roadwork zones must be captured and maintained. This is a responsibility of the road operator who is likely to outsource data capture and update tasks to the contractor in charge of the roadworks. Such data, e.g. recommended trajectory information, may be collected and provided by probe vehicles who already passed the roadwork zone (ADS operated or manually driven). Information service providers may be in the best position to collect driving history information from vehicle fleets. The road works zone information must be available digitally with sufficient level of accuracy and timely updates in case of changes. Information can be delivered to the ADS in several ways. One way is to build upon C-ITS deployment practices as documented by C-Roads and using C-ITS messages DENM, IVIM and MAPEM. Aside from direct short-range communication, information may flow through National Access Points and other backends of a third-party information broker and/or vehicle fleet operator. Alternatively, there may be a place and role for a Digital Twin, which is further elaborated by the CEDR 2020 DiREC project.

5.5 *Traffic jam use case description*

Use case introduction	
Summary	A vehicle operated by an ADS approaches a traffic jam or is driving in a traffic jam.
Background	It is assumed that without an intervention the ADS will approach and detect the traffic jam or detect that it dissolves, observe when the local conditions do not match the ODD of the system, and then transfer the dynamic driving task to the driver in case of a Level 3 ADS. In case of a Level 4 system the ADS will make a minimal risk manoeuvre. .
Objective	Timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.
Desired behaviour	The ADS can travel through traffic jam situations as normal, or it can transfer the control of the vehicle to the driver in a safe and timely manner. In case of the latter, the driver operates the vehicle through

	traffic jam situations or after the traffic jam dissolves, depending on which conditions violate its ODD constraints.
Expected benefits	With less ODD fragmentation, the ADS manufacturer can provide better continuity of service and thereby improve its competitiveness via improved attractivity to the vehicle buyer. In other instances, the ADS manufacturer can provide a smoother service when the dynamic driving task needs to be transferred to the vehicle driver. The driver can experience better continuity of services, with fewer interventions caused by transfer of control requests. In case the dynamic driving task does need to be transferred to the vehicle driver, the driver can experience a more user-friendly and informative service compared to the case with unexpected takeover requests. The road operator/ traffic manager experiences fewer minimal risk manoeuvres by ADS and fewer accidents in traffic jams due to safer driving behaviour of ADS.
Situation	2-lane motorway with hard shoulder, with a congested area with slow moving traffic with a length of 2 km. In the first scenario the ADS-operated vehicle is 2 km upstream of the traffic jam and approaching. In the second scenario the ADS-operated vehicle is driving in the traffic jam.
Actors and relations Note: actors are roles and not to be confused by stakeholders; an actor role can be fulfilled by any stakeholder (e.g. NRA), one stakeholder can have multiple roles.	ADS: performs the dynamic driving task and uses on-board and off-board sensors to create situational awareness. Upon detection of the traffic jam or that it dissolves the ADS assesses if it is capable to operate in the local conditions. If it is not, the system will request the vehicle driver to take over the dynamic driving task. Vehicle driver: is not performing the dynamic driving task. In case of a L3 system the driver must be available to resume the driving task when requested, in case of a L4 system the driver does not have to be available. The driver resumes the dynamic driving task if the ADS requests them to do so and if the driver is capable to do so. Road operator/traffic manager: operates the motorway by means of roadside systems and TMC services. It publishes information about the traffic jam via different communication channels to information service providers, vehicle systems and vehicle drivers. Information service provider: third-party information broker or vehicle fleet operator that facilitates the exchange of information between

	road authorities and fleet of vehicles which are operated by either vehicle drivers or ADS.
Use case scenario	Scenario 1: approaching a traffic jam, allow timely handover The road operator or traffic manager maintains and publishes detailed information about the location of traffic jams based on data from roadside sensors and probe vehicles. An information service provider ensures that the information is available to ADS. Upstream of the rear of the traffic jam the ADS receives information about the presence of the traffic jam. That information enables it to reduce its speed gradually upstream of the traffic jam, so that it can safely approach the stopped vehicles at the end of the traffic jam queue and avoid potentially hazardous situations when its forward sensors do not have sufficient range to detect the stopped vehicles from a full-speed approach. An alternate outcome for this scenario is that the ADS plans an alternative route and avoids the traffic jam. Scenario 2: in traffic jam dissolving, allow timely handover The road operator or traffic manager maintains and publishes an overview of the location of traffic jams based on information from roadside sensors and probe vehicles. An information service provider ensures that the information is available to ADS. Upstream of the front of the traffic jam the ADS receives information about the imminent dissolving of the traffic jam. If the ADS is not designed to operate outside traffic jams (e.g. speeds above 60 km/h), it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resume the dynamic driving task. An alternate outcome for this scenario is that the vehicle driver does not respond to the takeover request and the ADS initiates a minimal risk manoeuvre.
Functional constraints / dependencies	The information about traffic jams must be captured and maintained. This is a responsibility of the road operator who may use their own infrastructure sensors complemented with data from third-party service providers who likely use floating vehicle data. The traffic jam information must be available digitally with sufficient level of accuracy and timely updates in case of changes. Information can be delivered to the ADS in several ways. One way is to build upon C-ITS deployment practices as documented by C-Roads and using C-ITS messages DENM and IVIM. Aside from direct short-range communication, information may flow through National Access Points and other backends of a third-party information broker and/or vehicle fleet operator. Alternatively, there may be a place and role for a Digital Twin, which is further elaborated by the CEDR 2020 DiREC project.

Due to limitations of the range of in-vehicle sensors, in-advance information about adverse weather and traffic jam may enable ADS to better cope with those downstream local conditions. Especially the poor visibility due to weather combined with traffic jams is important. It is also relevant to provide in-advance information when the vehicle/ADS will drive out of a traffic jam or adverse weather zone, so that ADS can act appropriately. For the case of ALKS the basic aspects related to this use case scenario are illustrated in Figure 10.

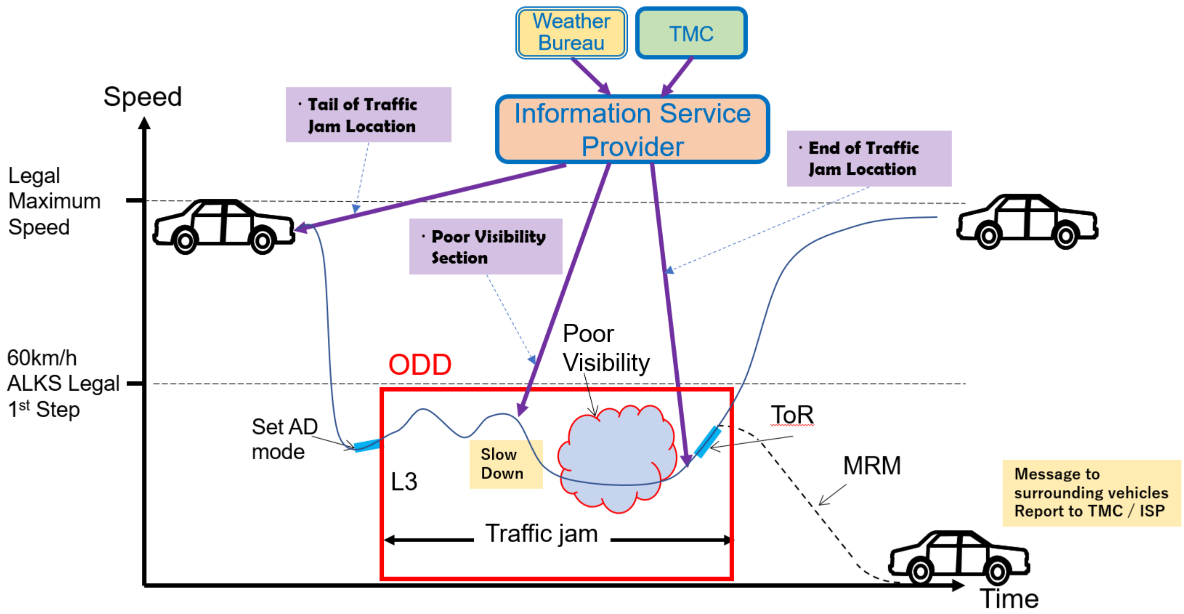

***Figure 10**: illustration of ADS in traffic jam and adverse weather area (courtesy of H. Kawashima)*

5.6 Tunnel use case description

Use case introduction	
Summary	A vehicle operated by an ADS approaches a tunnel or is driving in a tunnel.
Background	It is assumed that without an intervention the ADS will approach and detect the local conditions at the tunnel entry or exit, observe when the local conditions do not match the ODD of the system, and transfer the dynamic driving task to the driver in case of a Level 3 ADS. In case of a Level 4 system the ADS will make a minimal risk manoeuvre. .
Objective	Timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.

Desired behaviour	The ADS can handle the tunnel situation as normal, or it can transfer the control of the vehicle to the driver in a safe and timely manner. In case of the latter, the driver operates the vehicle at the tunnel situation.
Expected benefits	With less ODD fragmentation, the ADS manufacturer can provide better continuity of service and thereby improve its competitiveness via improved attractivity to the vehicle buyer. In other instances, the ADS manufacturer can provide a smoother service when the dynamic driving task needs to be transferred to the vehicle driver. The driver can experience better continuity of services, with fewer interventions caused by transfer of control requests. In case the dynamic driving task does need to be transferred to the vehicle driver, the driver can experience a more user-friendly and informative service compared to the case with unexpected takeover requests. The road operator/ traffic manager experiences fewer minimal risk manoeuvres by ADS and fewer accidents near or in tunnels due to safer driving behaviour of ADS.
Situation	2-lane motorway without hard shoulder with a tunnel with a length of 3 km. In the first scenario the ADS-operated vehicle is 2 km upstream of the tunnel and approaching, and the tunnel is temporarily closed due to an incident. In the second scenario the ADS-operated vehicle is driving in the tunnel.
Actors and relations Note: actors are roles and not to be confused by stakeholders; an actor role can be fulfilled by any stakeholder (e.g. NRA), one stakeholder can have multiple roles.	ADS: performs the dynamic driving task and uses on-board and off-board sensors to create situational awareness. Upon detection of the local conditions at the tunnel entry or exit the ADS assesses if it is capable to operate in the local conditions. If it is not, the system will request the vehicle driver to take over the dynamic driving task. Vehicle driver: is not performing the dynamic driving task. In case of a L3 system the driver must be available to resume the driving task when requested, in case of a L4 system the driver does not have to be available. The driver resumes the dynamic driving task if the ADS requests them to do so and if the driver is capable to do so. Road operator/traffic manager: operates the motorway and tunnel by means of roadside systems and TMC services. It publishes information related to the tunnel via different communication channels to information service providers, vehicle systems and vehicle drivers.

	Information service provider: third-party information broker or vehicle fleet operator that facilitates the exchange of information between road authorities and fleet of vehicles which are operated by either vehicle drivers or ADS.
Use case scenario	Scenario 1: approaching a closed tunnel, allow timely handover The road operator or traffic manager monitors tunnels continuously and publishes detailed information of temporary tunnel closures when an incident occurs. An information service provider ensures that the information is available to ADS. Upstream of the tunnel and the tunnel's signalling systems, the ADS receives information about the closure of the tunnel. As the ADS is not designed for this condition, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resume the dynamic driving task. Scenario 2: interpret the closed tunnel condition The road operator or traffic manager monitors tunnels continuously and publishes detailed information about tunnel closures. An information service provider ensures that the information is available to ADS. Upstream of the tunnel and the tunnel's signalling systems, the ADS receives information about the closure of the tunnel and active diversions via other lanes and/or tunnel tube. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, the ADS continues the dynamic driving task and stops the vehicle in the queue at the tunnel's signalling system or follows the active diversion. If not, it requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. An alternate outcome for this scenario, in particular when the duration of the tunnel closure is known, is that the ADS (likely the information service provider) plans an alternative route and avoids the tunnel. Scenario 3: approach tunnel exit, allow timely handover The road operator or traffic manager maintains and publishes detailed information about local conditions at tunnel exits (e.g., weather, incidents or lighting) based on information provided by roadside equipment. An information service provider ensures that the information is available to ADS. Upstream of the tunnel exit the ADS receives information about the local condition at the tunnel exit. If the ADS is not designed to operate in those conditions, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resumes the dynamic driving task. If the driver fails to respond the ADS will perform an MRM.

	Scenario 4: interpret the tunnel exit condition The road operator or traffic manager maintains and publishes *descriptive* information about local conditions at tunnel exits (e.g., weather, incidents or lighting) based on information provided by roadside equipment. An information service provider ensures that the information is available to ADS. Upstream of the tunnel exit the ADS receives information about the local condition at the tunnel exit. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving possibly with adapted driving behaviour (e.g. reduced driving velocity) or in-advance activation of functions that will mitigate the effects of the local condition on the ADS capability (e.g. heat the sensors). If not, the ADS requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. If the driver fails to respond the ADS will perform an MRM. Scenario 3: guided through the tunnel exit condition The road operator or traffic manager maintains and publishes *detailed* information about local conditions at tunnel exits (e.g. weather, incidents or lighting) based on information provided by roadside equipment. In addition, the road operator or traffic manager activates road management (e.g. lane closure) and/or traffic calming measures (e.g. reduced speed), which are also published. An information service provider ensures that the information is available to ADS. Upstream of the tunnel exit the ADS receives information about the local conditions at the tunnel exit. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving, possibly with adapted driving behaviour, if not it requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. If the driver fails to respond the ADS will perform an MRM.
Functional constraints / dependencies	Local condition information must be collected and frequently updated. This is a responsibility of the road authority who may use their own infrastructure sensors complemented with data from third-party service providers (e.g. meteorological institute and floating vehicle data). The local condition information must be available digitally with sufficient level of accuracy and timely updates in case of changes. Communication and connectivity require special attention in the case of local conditions at tunnel exits. As there may be no (mobile network) coverage in the tunnel, connectivity relies on short-range communication technologies for which reflection of radio waves should be taken into consideration. Alternatively, information may be

	delivered to the ADS before entering the tunnel with the risk of being outdated by the time the ADS exits the tunnel. In case of such long tunnels, it is necessary to deliver local condition information to ADS when they are driving in the tunnel. One option may be the use of visual signalling inside the tunnel which can be read by the ADS as well as by human drivers. Information can be delivered to the ADS in several ways. One way is to build upon C-ITS deployment practices as documented by C-Roads and using C-ITS messages DENM, IVIM and MAPEM. Aside from direct short-range communication, information may flow through National Access Points and other backends of a third-party information broker and/or vehicle fleet operator. Alternatively, there may be a place and role for a Digital Twin which is further elaborated by the CEDR 2020 DiREC project.

Figure 11 below illustrates the different scenarios which are described above. It shows different operational design domains which are directly related to the tunnel condition.

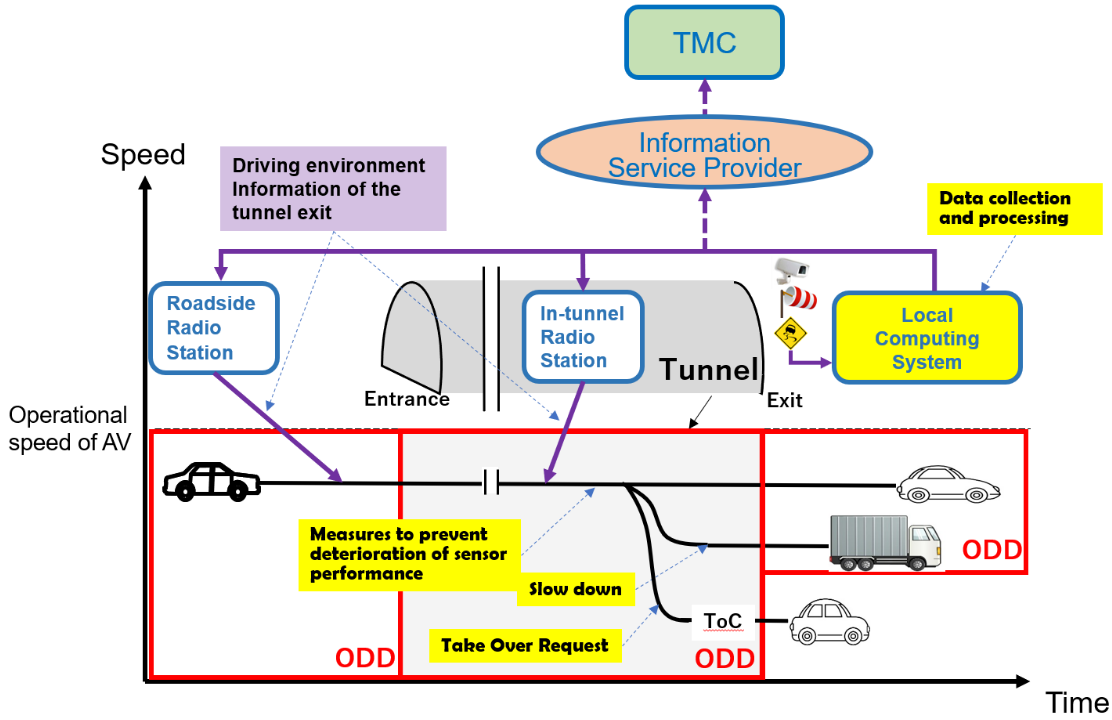

***Figure 11**: illustration of tunnel use case (courtesy of H. Kawashima)*

6 Opportunities for NRA and TMC core businesses

The core business of the road operators including road authorities have been identified by CEDR as according to **Figure 12**.

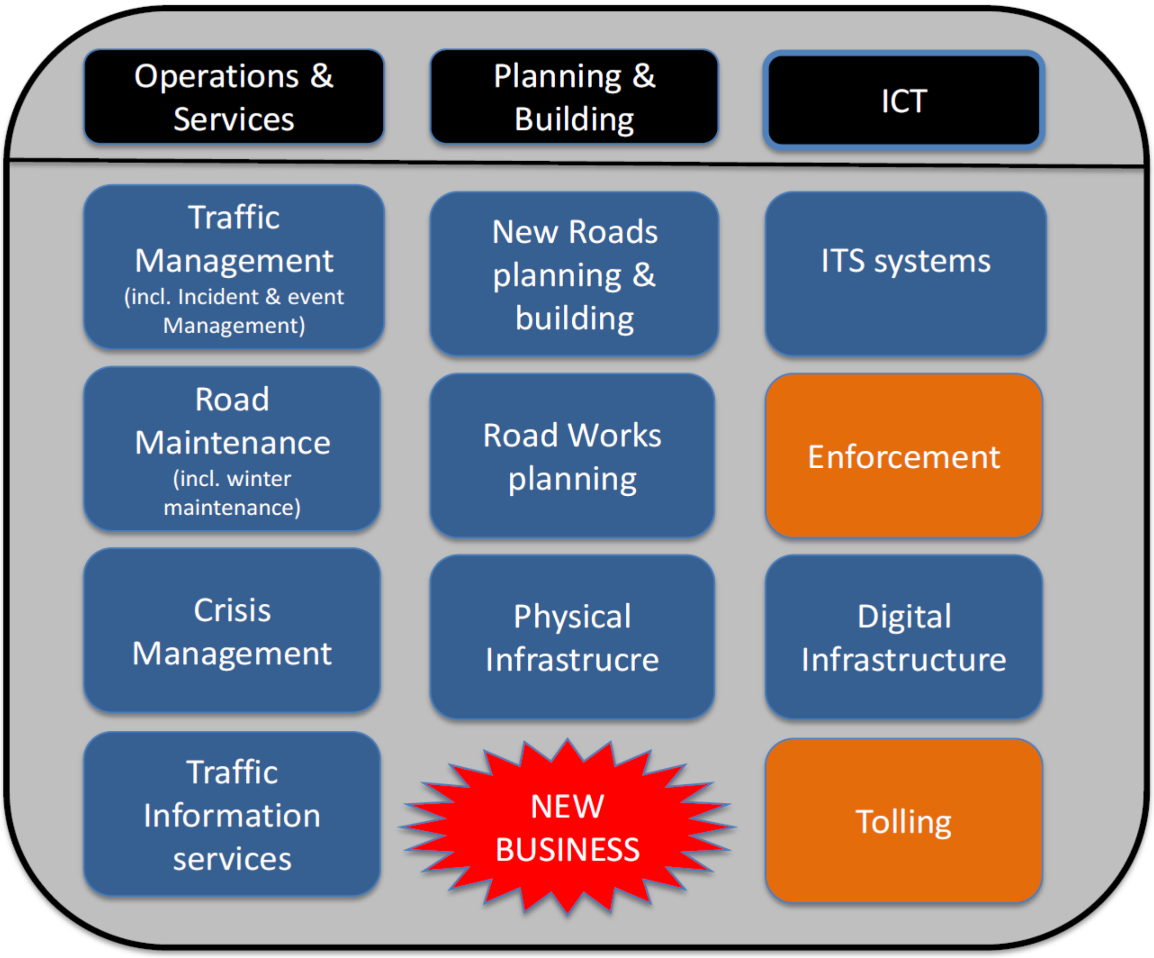

***Figure 12**: Road authority business areas (CEDR 2017).*

The MANTRA project utilised the following categories of the core business areas for studying the implications of highly automated driving on the NRA core business (Kulmala et al. 2020):

- Physical road infrastructure
- Digital infrastructure
- Operations and services
    - incident and event management
    - crisis management
    - traffic management and control
    - road maintenance
    - winter maintenance
    - traffic information services
    - enforcement
    - road user charging

- Planning, building, heavy maintenance
  - new roads planning and building
  - road works planning and management
  - heavy maintenance planning
- New business.

The opportunities are described in more detail for each of the core business areas. Note that the opportunities build on the availability of data from automated vehicles utilising the DOVA framework on e.g. the ODD unavailability, carrying out of MRMs, etc. The chapter assumes a much broader information provision from the vehicle side than the DOVA framework. It is likely that the road authorities and operators expect that in return for the ODD-related local condition information provided to the vehicles and fleet operators these would also provide information essential to the road authorities and operators.

6.1 Physical road infrastructure

Feedback from the automated vehicles concerning the issues related to the ADS engagement enable easier real time analysis of physical infrastructure driveability for highly automated vehicles. This also provides data on the frequency of different types of issues in various parts of the network.

If the AV fleet operators are willing the share the location and even in some cases the reasons for the issues with the road operator or traffic management centre, the latter can identify the problems related to their responsibility and find solutions to remove these problems. If the solutions are economically and otherwise feasible, the implementation of the solutions can take place.

The data from the automated vehicles on any problems related to the physical infrastructure will provide a new and important data source for the asset management processes of the road operator. This can relate to all physical infrastructure related ODD attributes such as for instance quality of pavement marking and the load-bearing capacity of roadway or bridge structures (Kulmala et al. 2022).

6.2 Digital infrastructure

The DOVA framework and vehicle originated data will also provide high quality tools for digital road operation.

The setting up of the DOVA framework already will indirectly provide improved quality data for all other digital road operator services as the local condition data required by the ADS has higher quality requirements than the conventional services (Kulmala et al 2022). Thereby the benefits to the existing services will also likely increase (Laine et al. 2021).

The improved and larger sets of data provide also a good basis for the use of AI (Artificial Intelligence) resulting in improved core business services utilising AI-enhanced digital infrastructure.

The data in the DOVA and provided in its feedback loop provide also an excellent basis for developing and enhancing the digital infrastructure asset management and its processes. This asset management would likely target at least the digital infrastructure oriented ODD data source such as the availability of GNSS positioning and its differential correction signals or I2V/V2I communications (Kulmala et al. 2022).

6.3 Incident and event management

The sensing by automated vehicles may well be the first source of information about an incident on the road. It could also be the first source to detect the effects of an event on or nearby the road resulting in a sudden end of a stopped or slow queue on the road.

The thereby improved location accuracy and timeliness of detection will provide quicker and more effective incident and event management services. In addition to location accuracy and timeliness, the automated driving system originated data will likely provide improved event coverage (proportion of incidents or events detected and reacted to) and road network coverage. The coverage will naturally only improve on roads within the ODD of the ADS systems in question.

In addition to the benefits related to incident and event impact detection, the ADS supported by DOVA are expected to react better to incident management and information measures complying more uniformly with them compared to human drivers. This will likely reduce the risks of secondary accidents and lessen the congestion caused by incidents and events and thereby also the journey time and harmful emission impacts.

6.4 Crisis management

Concerning crisis management, the same impacts apply for these comprehensive kinds of incident and events. Furthermore, new kinds of approaches to crisis management will likely be developed when there is a high penetration rate of ADS in use on the road network. This calls for a close integration of the actions of the traffic managers and ADS fleet operators.

6.5 Traffic management and control

The DOVA provides a possibility for tailored traffic management for different automated driving use cases and scenarios. This also will require a close cooperation and interaction between traffic managers and ADS fleet operators. This could lead to different types of ODD management use cases where traffic management measures and adapted rules of the road could control, maintain or eliminate the use of ADS on a road section ensuring road safety at the same time.

This merging of traffic and fleet management could be especially useful for managing hazardous or XXL goods transports (XXL here means goods with dimensions exceeding the ones accepted by regulations).

The ADS will also comply better with traffic management measures than human drivers. Higher compliance rate with regard to traffic management measures means that new methods of traffic management are required. Conventional traffic management measures for instance for rerouting result in only a moderate part of the vehicle drivers to divert accordingly, which in most cases is useful as high diversion rates could cause major congestion issues on the detour (EU EIP 2021). With ADS and their high compliance rate traffic managers need to direct the optimal portions of vehicles to specific detours based on the capacity and other characteristics of the detour (e.g. no heavy goods vehicles should be directed through small village communities).

If available, improved and more comprehensive real-time data in terms of floating vehicle data can be used in actual incident prediction and prevention via traffic management tools utilising AI. This can transform the current reactive traffic management to proactive traffic management where instead of reacting efficiently to incidents to mitigate their impacts and to remove them as quickly as possible traffic management focuses on preventing the incidents from occurring at all. This could be possible by detecting the first symptoms of a likely incident and start preventive measures accordingly in good time.

6.6 Road maintenance

The use of DOVA will accelerate the use of ADS also in automated maintenance vehicles. This in turn will affect the road maintenance operations and processes considerably. These vehicles could replace human drivers and operators of the vehicles carrying out the maintenance work or operate as automated safety trailers providing a shelter for the road workers. Depending on the type of maintenance, the road maintenance vehicles can require accurate digital twins/models of the road infrastructure and its environment. On the other hand, the maintenance vehicles themselves can facilitate the creation of accurate data models of the infrastructure.

The improved detection of defects or other maintenance needs in road and its environment by the sensors in automated vehicles can facilitate quicker and more effective road maintenance services. Thereby the improved asset management data source discussed earlier provides benefits also here.

6.7 Winter maintenance

With regard to winter maintenance, the impacts are very similar as for road maintenance. In conditions where the road is covered by e.g. snow or ice, the ADS with their accurate positioning can even perform more efficiently than human drivers of winter maintenance vehicles. The problems with black ice typically emerge during the night-time hours of declining temperatures coinciding with low traffic volumes providing an economically attractive and safe opportunity to utilise driverless winter maintenance vehicles.

6.8 Traffic information services

As with many other services above the data from vehicles in the DOVA feedback loop provide higher quality data about the transport system in terms of location accuracy, timeliness, error rate, latency, and event coverage. This will result in a considerable improvement of the quality of the information provided by the information services. In addition to the conventional services (EU EIP 2021) this will likely result in totally new services like ones targeting especially automated driving such as real-time services providing information on ODD availability or road network driveability useful for ADS routing.

6.9 Enforcement

The acceleration of the roll-out and take-up of automated vehicles will mean that the conventional enforcement oriented towards human drivers will become obsolescent in the long run.

At the same time, the evolution and especially the availability of data from ADS concerning the status of ODD attributes provides useful data for the road operators to enforce the operations and results of their road works, maintenance, incident and traffic management contractors and operators. Today this enforcement relies on routine manual checks by the road operator personnel or feedback from unhappy road users.

6.10 Road user charging

If privacy issues related to road user charging according to vehicle location in space and time can be solved, the DOVA can provide data for more detailed granularity of charging based on e.g. the ADS use and type of infrastructure support. For instance, ADS that have a track record of high risk of MRMs would be charged more, or provision of sufficiently high quality communication infrastructure support facilitating remote ADS supervision would be charged from the related ADS by the infrastructure providers. Costly operations such as re-activating vehicles from the minimal risk conditions or remote supervision could be priced dynamically by private companies providing such services.

6.11 New roads planning and building

The improved digital twins required by the provision of DOVA will benefit in providing input to more detailed digital twins for BIM (Building Information Modelling).

Furthermore, the physical infrastructure issues identified (see the discussion above) can be utilised in the planning of new roads so that the recurring road design related problems can be avoided in the future.

6.12 Road works planning and management

The need of the ADS for detailed status information about fixed and mobile road works zones provides for more efficient road works management where the operations will be more aligned to the standards and regulations. Today some contractors are more relaxed than others in terms of complying with the standards and regulations, which causes confusion and risks when human drivers have difficulties in navigation through the road works. The ADS will react in a tangible manner via take over requests and MRMs, which will likely initiate strong reactions from ADS fleet operators and individual AV users resulting in sanctions against non-complying contractors.

6.13 Heavy maintenance planning

The improved data requirements for DOVA result in also more detailed knowledge for AIM (Asset Information Modelling) resulting in improved heavy maintenance planning and also operations.

Furthermore, the physical infrastructure issues identified (see the discussion above) can be utilised in heavy maintenance planning.

6.14 New business

The digital road operator toolbox will benefit from the DOVA and the systems and processes implemented for them. Furthermore, the additional data expected from the ADS of the automated vehicles will provide a lot of new types of data that can be utilised for new kinds of business for the road operator or traffic manager.

In addition, automated driving and road operator support for automated driving can result in new tasks and roles for the road operator. These are briefly addressed below.

While ODD management is a task carried out by the individual ADS or the ADS fleet operators, the road operators may need to get involved in ODD management. Road operators will naturally provide data on local condition attributes relevant for the ODDs of the ADS, but they can in the future also specify the minimum capability of the ADS on their roads. This is useful if they have negative experiences of the effects of certain automated driving use cases on their roads in some specific situations related to ODD limitations. For instance, the road operators could demand that only ADS capable of negotiating road works zones are allowed to be used on their roads.

Remote supervision of ADS will take place to ensure vehicle occupant safety and security in specific cases where the ADS alone cannot continue the dynamic driving task and where the vehicle occupant cannot take over the control of the vehicle. Remote supervision can take the form of remote assistance or remote driving. In remote assistance, the remote supervision centre operator acts as a remote dispatcher, monitor or assistant to the ADS, which is responsible for carrying out the dynamic driving task. In remote driving, the centre operator acts as a remote driver responsible for all or some aspects of the dynamic driving task. The road operator can naturally provide data on local condition attributes relevant for the ODDs, but could also restrict the use of remote driving on their roads if they consider the road safety risks of remote driving too high.

However, the road operators could also allow remote driving in specific cases with specific restrictions. For instance, in the clearance of incidents, the police and road operator could jointly agree to permit an automated vehicle to be remotely driven away from the incident site at a low speed.

The restrictions on the use of remote driving as well as the minimum capability of the ADS could technically be handled by using geofencing.

The operation of the Distributed ODD attribute Value Awareness (DOVA) framework or participation in it could also become the business of the road authority and operator in the future, but this will depend on the mission and motivation of the road authority and operator, the national transport policies, and the stand of the vehicle manufacturers and the ADS developers and fleet operators. In any case, the road authority's and operator's role will be to make their own data on local conditions accessible to the DOVA framework.

7 Conclusions

The table below summarises the progress of this report with regards to answering research questions and expected project results.

Table 10: *progress on answering research questions*

Research Questions	Achievements and gaps
RQ2: Do brokers between traffic management centres and vehicles/OEM back ends add value in this interaction?	Information service provider can have a role in the distribution of information as is explained in section 5.2. An information service provider can be a third-party information broker or vehicle fleet operator that facilitates the exchange of information between road authorities and fleets of vehicles, which are operated by either vehicle drivers or ADS. TM4CAD has assumed that ADS decide if they can handle local conditions based on the ODD attribute value information is has available. In section 4.2 this is defined as the decentralisation, which implies that driving rules and expected driving behaviour must be defined in regulations and that ADS must continuously monitor if they can comply to those in addition to handling the complexity of the local condition. Centralisation offers an alternative perspective which is more common in Japan and presumes that a central entity interprets the local condition and assists the ADS to make the right decisions when performing the dynamic driving task.

Research Questions	Achievements and gaps
RQ3: How does CCAM support the work of traffic management centres and how can traffic management centres support and facilitate the deployment of CCAM?	TMCs and roadside equipment can support ADS by making ODD attribute value information available in-advance, for local conditions that cannot be sensed by on-board sensors. ADS (likely through information service providers) can support TMCs by collecting ODD attribute value information with their sensors, which can be aggregated by TMCs and in turn used to publish ODD attribute value information to a larger geographical area and/or vehicle fleet. The basic principles and examples of this exchange of information is discussed in section 3.4 and chapter 5. The premise of active traffic management, which is a longer term interest built on the expectation of better compliance of vehicles through ADS, thereby enable NRAs to better manage traffic volumes and traffic flow dynamics, requires further research. The adoption of DOVA by ADS developers may be an important stepping stone towards such a collaborate form of traffic management.
RQ6: When and how should such information be available?	Information can be made available for local conditions that are beyond the ADS sensor range and/or for which the ADS has limited capability to operate or meet the expected (desired) behaviour. Information beyond the line-of-sight of vehicle sensors is relevant for timely anticipation to the downstream conditions. Making information available in-advance allows timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition. This principles including use case examples are discussed in chapter 2, section 4.1 and chapter 5.

Research Questions	Achievements and gaps
RQ8: Are there any circumstances under which the traffic control centre would need to lower the ISAD level in order to stop automation taking place, or vice versa: to impose automated driving?	In TM4CAD we have framed the operating mechanism differently as is discussed in sections 1.4, 3.2 and chapter 5. In the context of DOVA, lowering (or increasing) the ISAD level would mean to stop the provision of information to decrease the ODD attribute value awareness of ADS. If awareness of a particular ODD attribute value is crucial for the ADS to operate, the implication of withholding that information could – in theory – be that automation is stopped (or reversely: initiated). Since the decision to operate in a local condition is entirely up to the ADS and the result of careful assessment of many factors, it is likely that the consequences are more nuanced when considering the variety of brands and classes of ADS. In addition, reduced ODD attribute value awareness may lead to more frequent transfer of the dynamic driving task to the driver and/or minimal risk manoeuvre in case the driver does not respond and for Level 4 systems.

***Table 11**: progress to essential results*

Essential Results	Achievements and gaps
ER1: Determination of the circumstances (actual traffic conditions, status of the infrastructure, …) under which the traffic control centre would need to lower the ISAD level in order to stop automation taking place and accordingly mitigating measures if applicable	See the response to RQ8. To date, there is no consensus among ADS developers and road authorities about the set of local conditions (circumstances) which require the provision of ODD attribute value information by NRAs. In Kulmala et al. (2023) we have discussed information needs and quality for several use cases and for an extensive list of attributes. Local conditions that cause ODD departure may be planned or unplanned and have variable or fixed location. This differentiation gives some guidance for structuring the dialogues and categorise local conditions. It is further discussed in chapter 2. The interpretation of local condition information is another factor for handling local conditions and taking mitigation measures. In chapter 4 we discuss different models and distinguish between centralisation and decentralisation. In case of the latter the ADS decided if it can operator or not, in case of the former an information service provider of some sort fulfils that role.
ER2: Determination of the circumstances under which the traffic control centre would need to upscale the ISAD level/impose more automated driving	See the response to ER2.
ER5: Definition of the roles and responsibilities in the interaction between OEMs/Service Providers and NRAs on operational level	In the context of Distributed ODD attribute value awareness, the role of the NRA is to provide off-board information to ADS, typically through roadside signalling equipment or digital cloud-based solutions. NRAs can provide information to vehicle drivers and ADS directly and/or via information service providers. Reversely, ADS can be an information source by sensing local conditions with on-board sensors and collect and provide probe vehicle data. NRAs can benefit from this probe vehicle information once it is aggregated to obtain a better understanding of the local conditions on the road network. In fact, this information can enable the road operator / traffic manager to provide local condition information to other actors. These and other interactions are discussed in sections 4.2 and 5.2.

***Table 12**: progress to optional results*

Optional Results	Achievements and gaps
OR1: Description of the possible added value of service providers in the interaction between NRAs and OEMs;	See the response to ER5. An information service provider can be a third-party information broker or vehicle fleet operator that facilitates the exchange of information between road authorities and fleets of vehicles, which are operated by either vehicle drivers or ADS. Information service providers can aggregate information coming from other specialist actors. This is discussed in more detail in section 5.2. In chapter 4 we distinguish between centralisation and decentralisation as two possible organisational structures. In case of the former, one extra added value of the information service provider is to interpret local condition information and provide active guidance to vehicle fleets. Considerations for both organisational structures are discussed in section 5.2.

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Appendix A: Message sets

Depending on the information that needs to be sent/received, a suitable container needs to be used. These typically take the form of the so-called CAM, DENM, MCM, CPM, MAPEM/SPATEM, IVIM; and MCDM V2X message sets.

- The **Cooperative Awareness Message (CAM)** is a message created by the Cooperative Awareness (CA) service residing at the Facilities layer of the ETSI ITS communication architecture stack. CAMs are exchanged between C-ITS stations equipped with V2X technology (i.e. vehicles, infrastructure stations, etc.) to create and maintain awareness of each other and to support cooperative performance of vehicles using the road network. CAMs provide information about presence, position, dynamics and basic attributes of the originating station. The received information can be used to support several C-ITS applications. For example, by comparing the position and dynamics of the originating station with its own status, a receiving station is able to estimate a collision risk.
- The **Decentralized Environmental Notification Message (DENM)** is another Facilities layer message. It contains information related to a road hazard or abnormal traffic conditions such as the type of event and its position. It is employed to alert other road users about the occurrence of an unexpected event that has potential impact on road safety or traffic condition. The DENM is also considered for Day1 deployment.
  The management of a DENM transmission depends on whether the vehicle is the generator of the message or a forwarder. For example, a vehicle may inform other vehicles about an emergency brake, in this case, the source vehicle generates the transmission and termination of the DENM. However, in other situations like for example in presence of black ice on the road, the event will be persistent once the vehicle that detected the black ice has left the area. In this case, the DENMs will be relayed by other ITS stations (as long as considered valid) and the DENM will be terminated once an ITS station detects that the black ice disappeared.
- The **Collective Perception (CP)** service uses **CP Messages (CPMs)** to transmit data about locally detected objects (i.e. non-cooperative traffic participants, obstacles and alike) to improve situational awareness. By exploiting the increasing sensing and communication capabilities of future vehicles, CP is considered by the car industry as a natural key enabler for cooperative automated driving applications. For this reason, CP standardization has been recently started at ETSI ITS at later stages of deployment (Day 2 and beyond). ETSI CPMs foster sustainability and interoperability by transmitting abstract representations of detected objects instead of type- and vendor-dependent raw sensor data. In addition, CPMs abstract descriptions can derive from detections made by single sensors or by result of local sensor fusion algorithms, which provides implementation flexibility. The CP is designed to allow sharing detections made by both vehicles and roadside infrastructure (RSI). For this purpose, detected object descriptions are shared referred to a coordinates system that is different according to the nature of the CPM originating station. In the case of a vehicle, xy axes take origin from its center-front and change direction as the vehicle moves. This is not suitable for static RSUs. Here, the adopted coordinate system is centered on a reference point placed close to the RSU with xy aligned to east and north, respectively, as for SPAT/MAP representation. Receiving stations map received object descriptions onto their local coordinate system. To allow this mapping, originating stations shall always transmit data about their coordinate system (e.g. reference point, and for vehicles also speed, orientation, etc.). Besides this, they shall communicate their detection capabilities in terms of installed sensors' Fields of View (FoV). When

receiving a CPM with no object detected in a given direction, a CAV can make a cross-check by analyzing the FoV information: if it says that the originating station has no sensors covering that direction, objects can be actually present in reality.

- The ETSI TC ITS is currently defining the **Maneuver Coordination Message (MCM)** which can be used to coordinate maneuvers between ITS stations. The MCM is at early stage of standardisation.
- The **Map Message (MAPEM)** is an I2V message used by the RSI to convey many types of geographic road information. At the moment the MAPEM is used to convey one or more intersection lane geometry information within a single message. The message content includes items such as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). The contents of this message define the details of indexing systems that are in turn used by other messages to relate additional information about events at specific geographic locations on the roadway. Most commonly used examples of this kind are the signal phase and timing via the **Signal Phase and Timing (SPATEM)** message. The SPATEM message is used to convey the current status of one or more signalized intersections. Along with the MAPEM message (which describes a full geometric layout of an intersection) the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur.
  The MAPEM message is the effective result of the Road and Lane Topology (RLT) infrastructure service which manages the generation, transmission and reception of a digital topological map. This service along with its operational parameters is defined in ETSI TS 103 301, which in turn refers to the SAE J2735 data dictionary. Being part of the Day 1 deployment in Europe, data elements, data frames and service parameters of the MAPEM shall be used according to the definitions provided by the C-ITS Infrastructure Functions and Specifications of the C-Roads Platform.
- The **In-Vehicle Information message (IVIM)** is an I2V message format conveying information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency. For the first phase of C-ITS deployment in Europe, C-Roads and the C2C-CC have agreed on adopting IVI profiling examples based on the IVI message format standardized in ISO TS 19321. In turn, this standard refers to the sign catalogue established by ISO TS 14823, which presents standardized codes for existing signs and pictograms used to deliver Traffic and Traveller Information (TTI). The IVIM message transmission is operated in accordance to the standard ETSI TS 103 301, which describes facilities layer protocols and communication requirements for infrastructure-based services. Similar to other ETSI C-ITS messages, an IVI PDU is encapsulated in the ItsPDUHeader and transmitted as IVIM through the lower layer of the communication stack.
- The ETSI TC ITS is currently defining the **Multimedia Content Dissemination Message (MCDM)** in order to share multimedia content between ITS stations describing events for different application. For example, a road safety application can employ pictures or videos about obstacles on the road. Similarly, a traffic management application can employ pictures or videos about the traffic conditions in a specific area. Multimedia information provides enriched data that can improve the environmental perception or the perception of products and services locally available (i.e. electric vehicle charging spots, national patrimony information, etc.).