Traffic Management for Connected and Automated Driving (TM4CAD)

Information exchange between traffic management centres and automated vehicles – information needs, quality and governance

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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. 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 objective of this report is to specify the crucial properties of the information exchange including the content, timing, quality, and governance of the information.

The report build on the information needs of three actors (automated driving system developers/OEMs, traffic managers and road works/maintenance operators) in three scenarios of traffic jam dissolving, adverse weather area and road works zone of SAE Level 3/4 vehicles on highways and motorways.

The information needs are discussed for each actor and scenario utilising the Distributed ODD attribute Value Awareness (DOVA) framework developed by TM4CAD and its ODD or local condition attributes.

The information attributes are then 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 all, seven physical infrastructure, eight digital infrastructure support, sixteen ambient environmental conditions, and nine operational roadway condition related local condition attributes were regarded as high-priority ones for providing ODD attribute value awareness.

Furthermore, the report describes the quality indicators for the DOVA framework and its data contents and provides recommendations for quality recommendations in the future when the L3/L4 vehicles have a considerable share in the traffic flow on highways. The quality requirements are higher than today, especially with regard to the location accuracy and timeliness-related quality indicators. The higher requirements can be reached, however, by the connected and automated vehicles providing the related data to the DOVA framework operator. Likely methods to be used for quality assessment and assurance are also shortly described.

The methods, processes and standards for the exchange of the data within the DOVA framework are described to reach a feasible practical solution for harmonised data exchange.

The issues in the governance of the DOVA are discussed in the light of the contextual background and the 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 a public-private partnership, in which the government also commits itself to providing information and data according to pre-agreed upon specifications.

Finally, the report concludes with summarizing the answers to the Research Questions to be addressed, listing the major remaining open issues and implications for further work. An important next step is to validate the findings for a specific use case and scenario, which will likely be the road works zone.

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Acronyms and abbreviations

Acronym	Definition
ADS	Automated Driving System
ALKS	Automated Lane Keeping System
AV	Automated Vehicle
BSI	British Standards Institution
CAD	Connected and Automated Driving
CAV	Connected Automated Vehicle
CCAM	Cooperative Connected Automated Mobility
CEDR	Conference of European Directors of Roads
CEF	Connecting Europe Facility
CEN	European Committee for Standardisation
C-ITS	Cooperative Intelligent Transport Systems
DATEX II	Data exchange standard for exchanging traffic information
DOVA	Distributed ODD attribute Value Awareness
DoRN	Description of Research Needs
ECU	Engine control unit
EU EIP	EU ITS Platform
ETSI	European Telecommunications Standards Institute
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High definition
I2V	Infrastructure-to-Vehicle (communication)
ISAD	Infrastructure Support for Automated Driving
ISO	International Standardisation Organisation
ITS	Intelligent Transport Systems
L3	Level 3 (driving automation)
L4	Level 4 (driving automation)
LTE	Long Term Evolution
MRM	Minimal Risk Manoeuvre
NAP	National Access Point
NRA	National Road Authority
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PAS	Publicly Available Specification
PEB	Programme Executive Board
PIARC	World Road Association
RQ	Research Question
RTTI	Real-Time Traffic Information
SAE	Society of Automotive Engineers
SRTI	Safety-related traffic information (Directive)
TM4CAD	Traffic Management for Connected and Automated Driving
TMC	Traffic Management Centre
TMS	Traffic management system
ToC	Transfer of Control
V2I	Vehicle-to-Infrastructure (communication)
V2X	Vehicle-to-Everything (communication)

Acronym	Definition
VMS	Variable Message Sign
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. The distributed ODD attribute value awareness (as a state of the ADS) means that the ODD attributes' values known to the ADS are obtained through a combination of on-board and off-board sensors. As a starting point we proposed various approaches for providing distributed ODD attribute value 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 two real-world use cases, which build on the premise of interaction between traffic management systems and CAD vehicles. This provided 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;
- Introduce 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 should be refined for traffic management use, and
- Detailed how traffic management systems and CAD vehicles can best interact to improve traffic operations.

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

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

1.2 Objectives

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. 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 objective of this report is to specify the crucial properties of the information exchange including the content, timing, quality, and governance of the information.

1.3 Research Questions and Expected Outcomes/Outputs

The following Research Questions (RQ), Essential Results (ER) and Operational Results (OR) from the larger list addressed by TM4CAD are tackled by this deliverable D3.1:

Table 1-1: *Mapping of Research Questions and Expected Results to Deliverable 3.1*

Research question / result	Addressed in chapter(s)
RQ4: What kind of information is to be transmitted in the interaction (in both directions) between TMC and vehicle?	Chapters 2 and 3
RQ5: Which information is to be provided by the NRA/roadside and which information can be obtained by the sensors of the moving vehicle itself?	Chapter 6
RQ6: When and how should such information be available?	Chapters 2, 4 and 5
RQ7: How to define and measure the quality/correctness of such information?	Chapter 4
ER3: Determination of the information needs and who is to provide this information in the bidirectional interaction between TMC and vehicle	Chapters 2 and 3
ER4: Description of the properties of this information (availability, reliability, accuracy, detail, latency, standards, …) and the required/desired reaction of the vehicles;	Chapter 4
OR2: Description of possible governance mechanisms for ODD management that need to be established;	Chapter 6

1.4 Relationship with other Work Packages

This WP was carried out utilising the results of projects like DIRIZON, MANTRA, INFRAMIX, TransAID, C-Roads, NordicWay 3 etc. as well the discussions in the CCAM Platform's relevant WGs and interviews of stakeholders in Europe, Japan and the U.S. The information needs were validated in a European workshop targeting NRAs, traffic managers and OEMs.

In TM4CAD, WP2 was the primary source of input concerning the information needs. The WP results were utilised in WPs 4 and 5 as well as eventually also in WP2's completion. The results of WP4 and WP5 have led to the updating of the WP3 results in the last months of the project.

1.5 Distributed ODD Attribute value Awareness (DOVA) Framework

The need to monitor or be aware of the current value 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. However, 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 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 either inside or outside its ODD.

While information for some of the ODD attributes could be available via infrastructure, there may potentially 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 end of their ODD and/or being in a transitional or minimal risk state.

The operation of the DOVA framework in practice is illustrated in Figure 1-1. 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.

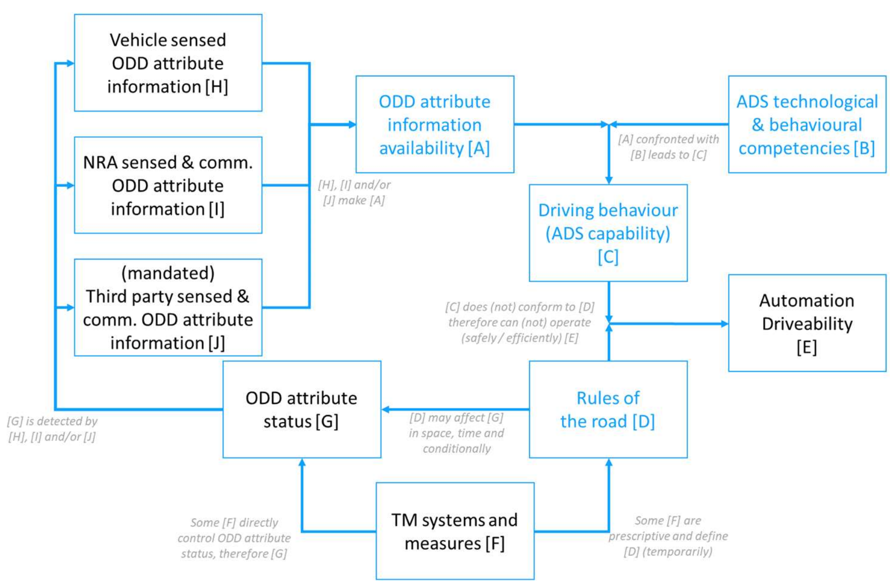

Figure 1-1. Distributed ODD Attribute Value Awareness Framework

1.6 Use cases

The use cases consist of two main dimensions: 1) ADS and 2) scenery/environment (part of ODD attributes). Both of these dimensions affect the information and information exchange needs of an automated vehicle under ADS control. The ADS determines the ODD attributes, and the ambient conditions affect the quality, importance and urgency of the various attributes in those specific situations.

With regard to the driving environment, we focus on motorways or similar dual carriageway roads and three specific scenarios of:

- traffic jam (or its dissolving)
- adverse road weather (fog, rain, snow, ice)
- fixed or mobile road works

The scenario choice is aligned with the ODD fragmentation scenarios targeted by the vehicle manufacturers. The Hi-Drive project (Bolovinou et al., 2023) lists traffic volumes, adverse road weather and construction sites as scenarios that it addresses on motorways in addition to e.g., tunnels, road hazards, deteriorated road markings and GNSS shortage.

A preliminary analysis of the information needs shows that the ODD information needs for Level 3 Automated Lane Keeping System (ALKS) or Traffic Jam Chauffeur and Level 4 Highway Auto Pilot are very similar to one another even though there is a fundamental difference in that Level 3 requires a human intervention to ensure safety, while Level 4 can ensure safety without human intervention via a minimal risk manoeuvre. For that reason, the ODD attribute information needs of these ADS can be dealt with together. Automated trucks on motorways also mostly have similar demands except for the truck platooning ADS. Truck platooning is not be covered in this deliverable.

All Level 3 use cases have two scenario paths: one without and one with request for Transfer of Control (ToC) also known as request to intervene (RTI) from the ADS to the human vehicle occupant resulting in the ToC or a Minimal Risk Manoeuvre (MRM). In the case without ToC the vehicle adapts its driving behaviour (e.g. slower speed, more cautious) in order to deal with the driving conditions and to stay within the ODD. In all cases, we assume that regardless of whether the driver voluntarily chooses to intervene or intervenes in response to an RTI from the system, the driver will take over **full** control of the vehicle driving task (i.e. return to level 0 and not 1 nor 2). This transition can be facilitated if the driver is given a prior alert to pay attention to the driving environment and if sufficient time is available before the intervention is necessary. Naturally the driver can later re-engage any driving automation systems when the ADS' ODD conditions are satisfied. Level 4 systems do not require any human intervention but are (by definition) able to perform fallback to achieve a minimal risk condition (stopped and stable) by themselves.

Hence, the use cases are:

- Traffic Jam Chauffeur/ALKS/Highway Auto Pilot + traffic jam (+ TOC/MRM)
- Traffic Jam Chauffeur/ALKS/Highway Auto Pilot + adverse road weather (+ TOC/MRM)
- Traffic Jam Chauffeur/ALKS/Highway Auto Pilot + road works (+ TOC/MRM)

The focus is on highways including motorways. The examples described below deal with cars but are applicable to other motor vehicles as well. The vehicles are assumed to have connectivity and access to infrastructure communications via various technologies.

Traffic jam (or its dissolving)

The forward sensors on ADS-equipped vehicles have limited range, and it is particularly challenging for them to discriminate stopped vehicles from stationary roadway infrastructure features such as bridges and signs. The range limitations are such that these become the primary limiter on the speed at which each ADS is capable of operating safely on motorways. When the ADS is operating at its design speed limit, the detection of a stopped vehicle in its path is likely to require a strong braking response, which raises the risk of a secondary crash if the vehicle behind the ADS-equipped vehicle is driven by an inattentive driver. The safety and speed range of the ADS can be enhanced if the ADS is supplied with external information about the location of traffic jams on any section of motorway that it enters, so that it can reduce its speed gracefully before its forward sensors can confirm the presence of a stopped vehicle in its path.

Traffic jam dissolving is a relevant use case for an ADS only capable of L3/L4 operation when speeds are low. This has been the case for the initial ALKS implementation of Traffic Jam Pilot (TJP), for instance. The ADS needs to be aware of when the traffic flow speed is low due to recurring or non-recurring congestion and the DOVA framework will provide that information in advance to the ADS. As a result the ADS will be ready to take control of the vehicle as soon as the driver requests the engagement of the system after it enters the congested road section and the vehicle's own sensors also confirm the situation.

The end location of traffic that is operating within the operational speed range of the L3/L4 operation cannot be recognized by the ADS by using only its in-vehicle sensors until it has actually reached that location. It is helpful for the ADS to know in advance when the vehicle needs to be controlled by the human driver again in order to issue an early request to intervene to the driver, allowing for a graceful transition of control. The location of the end of the traffic jam is provided by the DOVA framework.

Adverse weather

Adverse weather is the most critical situations for the ADS due to the limited capabilities of their in-vehicle sensors. Automated driving may still be possible by the help of information from infrastructure accompanied with e.g. reducing the speed of the AVs.

For an AV approaching a traffic jam caused by adverse weather the ADS behaviour is quite similar to the case of traffic jam. Since the performance of in-vehicle sensors is deteriorated by the weather, the ADS reduces the speed of the vehicle to maintain its safety.

The ADS can be a full-speed-range Level 3 system controlling the vehicle for a longer time before it encounters a road section with adverse weather conditions. The ADS benefits from advance information about these conditions in order to be prepared to adapt the AV behaviour such as speed and following headway to the conditions in order to continue automated vehicle operation. It is also beneficial for the ADS to receive information about the end of the adverse weather section and the local conditions after that to facilitate safe operation after the adverse road weather section.

Unfortunately, current ADS cannot cope with the difficulties caused by all adverse road weather conditions and therefore in some situations encountering the most severe road weather may also lead to the need for human takeover of vehicle control or MRM.

Road works

Fixed road works zones or mobile road works vehicles on the road may interrupt the ODD of the ADS. The interruption may be avoided if the ADS is aware of the correct behaviour and trajectories needed to navigate through the road works zone or past the mobile road works vehicles.

If the ADS encounters a road work zone without any prior information about it the ADS may not be well prepared for the road works. In this case the request to intervene may be made very close to the road works when the vehicle sensors detect the obstacles associated with it and this can surprise the driver, resulting in sudden reactions and possible need for an emergency stop or MRM.

If the DOVA provides the ADS in-advance information of the location of the road works where ADS is not capable of performing the DDT, the request to intervene can be issued well enough in advance on the approach to the road works zone. This makes the driver well prepared to take the control of the vehicle before entering the road works zone.

In the future, the DOVA information may well include accurate information from the local traffic management about the road works and provide a recommended trajectory to the ADS. For some ADS this enables keeping within the ODD and continuing in the L3/L4 mode throughout the road works. For other ADS this still may lead to end of ODD and transfer of control to the driver.

1.7 Structure of this document

This deliverable starts by a description of information needs for the main stakeholder roles involved in the DOVA framework i.e., those of the traffic manager (usually the road network operator), the ADS of the automated vehicle, and the maintenance contractor responsible for the winter or road maintenance actions provided in the road environment in question.

The next chapter discusses the prioritisation of these information needs for these stakeholder roles and proposes a common view of the priorities for these stakeholders.

The deliverable continues by elaborating on the quality of information exchanged. The starting point is a proposal for the quality indicators to be used and the information quality indicators already identified for the real-time and safety related information services in Europe. We study the quality needs for the information for each use case and propose minimum quality levels for each of the selected indicators aiming for a use case agnostic recommendation. Finally, we propose feasible methods for quality assessment and management.

The next chapter looks in detail at the harmonisation of data exchange focusing on the content of the data to be exchanged while also listing the existing solutions and standard interfaces and protocols applicable for the DOVA framework operation.

Next, we elaborate on the governance of the information originating from the different sources as well as the governance of the information exchange in the DOVA framework.

This deliverable ends with conclusions listing the responses to the research questions, the identified gaps in knowledge, and the next steps to be taken.

2 Information needs

2.1 Method of information needs assessment

This chapter summarizes the information needs of the three actors of road works or maintenance operator, traffic manager and automated vehicle or driving system developer. The choice of the actors was based on their position as a data provider and consumer with regard to local condition information and at the same time ODD attribute information as well as their close relationship with either road operators or automated vehicle providers. Service providers have also a strong role as a local condition data provider and consumer, but their relationship with either road operators or automated vehicle providers in any actual use case scenario is only indirect via their products utilised by either. In addition, they are very heterogeneous with regard to the type of information provided. Thereby they were not included as one of the actors studied. Concerning the automated vehicle, a key future user of the information will be the fleet operator or manager responsible for a specific fleet of automated vehicles. Thereby the results for the ADS developers are meant to be also applicable for the AV fleet managers and operators.

Each actor's information need was analysed in the three use case scenarios of traffic jam, adverse weather area and static/dynamic road work zone. The analysis is based on the TM4CAD experts' knowledge and expertise validated in the TM4CAD workshops targeting vehicle manufacturers and CEDR members. The full analysis is presented in four tables in chapter 2.6.

The analyses followed the four local condition / ODD attribute categories presented originally in the TM4CAD Deliverable 2.1 "Report on ODD-ISAD architecture and NRA governance structure to ensure ODD compatibility": 1) physical attributes of the roadway and its environment, 2) digital infrastructure support, 3) dynamically varying ambient environmental conditions, and 4) operational attributes of the roadway. These are explained in more detail in chapter 2.2.

Methods to analyse the information needs were TM4CAD project members' assessment, a survey from a workshop discussion with automated vehicle industry members, and review feedback by road authorities of CEDR CAD Working Group. In addition, the Finnish LIHA 2.0 unpublished report was utilised to gather road maintenance operators' views.

The three actors were selected based on their relevance for the selected automated driving use cases and considered for each scenario: road works or (winter) maintenance operator, traffic manager and automated vehicle (Automated Driving Systems, ADS) developer or operator.

Following considerations from the analyses should be considered. First, assuming traffic manager and ADS developer have the same interest in safe automated vehicle manoeuvres they also have the same information needs and priorities to support each other, i.e., bidirectional benefits exist in many of the local condition / ODD attribute cases. Secondly, when the goal is safer traffic, the actors aim to avoid highest negative impact (e.g., crash) in their operations, which leads to precautionary risk management in low probability events and furthermore priority of attributes that provide relevant safety critical information. Thirdly, the complex and infinite scenarios of automated driving as well as possible data fusion of multiple ODD attributes by the actors (TM and ADS developer) are a major challenge for the analysis. Thereby a single local condition / ODD attribute in a scenario might not fully reflect the information need priority as the individual attribute can be a part of a function with multiple attribute variables that add up in the data fusion. For example, although one single local condition / ODD attribute of a physical road infrastructure such as game fence existence might present a low information need by itself, it might add high importance to a function of safe adverse weather automated driving together with multiple other local conditions or ODD attribute variables such as low visibility. Fourthly, this analysis only considers automated vehicle information needs from the ADS perspective and does not take account of the human driver information needs, which can be different.

2.2 Local condition and ODD Attributes

The Automated Driving Systems (ADS) on the vehicles must be able to identify whether the local environment in which they are driving satisfies their ODD constraints in order to meet basic functional safety requirements. However, they cannot be expected to know about different situations and conditions that may prevail outside the range or detection capabilities of their sensor systems. Many vehicle manufactures are deploying data exchange with other vehicles of the same manufacturer to deal with this problem and these could be extended to other vehicles in the future. In any case, this is where intelligent road and traffic management infrastructure can provide important support, informing the ADS about changes in traffic or weather conditions beyond in-vehicle sensor capabilities so that corrective action can be taken by the vehicles or their drivers. This could involve giving drivers ample advance notice about the need to intervene in the driving task, rerouting the vehicle away from a trouble spot, switching the automated driving into a degraded mode of operation, or as a last resort transitioning the vehicle to a minimal risk condition.

Thus, ODD constraints are especially important for higher levels of automation — SAE levels 3 and 4. In order to understand whether its ODD limitations are at risk of being violated, the ADS needs to be aware of the relevant ODD attributes (e.g., visibility, traffic density, incidents, etc.) in real time to compare them with the design ODD of the system. While some ODD attribute information can be sensed by the automated vehicle's on-board sensors, some information can only be supplied by off-board sources such as remote sensors and wireless communication systems. Levels of Infrastructure Support for Automated Driving (ISAD) have been defined as a general way of classifying available roadway infrastructure features that could affect the ODD constraints of CAD systems (Lytrivis et al. 2019; FTIA 2021).

ODD essentially defines the operating conditions for which an ADS is designed. It may also be seen from the perspective of the road operators as the operating conditions in which a system should be able to operate safely. It is essential that there be an overlap between the two perspectives on the ODD, CAV manufacturer (or the ADS designer) and the road operator, for ensuring the safe deployment of ADS.

As per SAE J3016, Operational Design Domain (ODD) is defined as "Operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics" (SAE 2021). ODD definition is key to both the system design and safety assurance process of an ADS.

The attributes used to define the ODD represent the combination of all the design factors that affect the ability of any ADS to perform its automated driving functions. They are likely to vary among different ADS, especially among systems that are intended to perform different transportation functions, delivering different transportation services. The ODD attributes are also important discriminators among different ADS, since the most primitive or limited capability systems will have the tightest ODD limitations while the most sophisticated and higher capability systems will have fewer ODD constraints on their ability to drive in an automated manner. At the earliest stage of introduction of ADS to public service, the ODD restrictions will be most significant, but as the technology advances the ODD restrictions may gradually be relaxed and become a less serious constraint on when and where the ADS can be used. However, it is important to highlight that all ADS will at all times have some level of restrictions as per their ODD definition. Another way of viewing this is to consider that the strongest infrastructure support for automated driving will be needed at the time of market introduction, but the need for that support will gradually diminish over time.

As a starting point we identified a wide range of ODD attributes that are relevant to determining the feasibility of ADS operations on highways, the measures of effectiveness for quantifying those attributes, and the ways of providing that attribute information to ADS-equipped vehicles for each highway segment, ultimately to enable ADS to be aware of their ODD in real-time. The attributes were specified according to the standard ODD taxonomy (BSI 2020) and then complementing them with some specific attributes identified in the Physical and Digital infrastructure Working Group of the CCAM Platform (CCAM WG3 2021) and the Finnish AUTOMOTO study (FTIA 2021).

One of the implicit requirements of defining an ODD is the need to monitor/measure or be aware of each of the attributes used in the ODD definition, in real-time. This is essential to establish if the ADS is inside or outside its defined ODD boundary. As mentioned earlier, the early deployments of ADS will have constrained ODD definitions, which in turn would require the ADS to implement a mechanism to be aware of its current local conditions and compare the same with its defined ODD.

While it may be possible to have onboard sensing for some of the attributes (e.g., road layout via HD maps etc.), for certain attributes (e.g., visibility range) the CAD system may not be able to measure via onboard sensing systems. In such cases, it will need to depend on off-board sensing mechanisms (e.g., a weather station or traffic management centre or fleet management centre) to provide real-time information about ODD attributes' values. We call such an architecture a Distributed ODD attribute Value Awareness (DOVA) architecture, which will be essential for safe and early deployment of CAD systems.

As the CAD system will depend on off-board sensing systems, there will be an implicit requirement on the connectivity attribute of the ODD. For example, due to the safety critical nature of the information about certain attributes, the ADS may require a given latency and signal strength specifications for it to ensure safe operation. Enabling such an infrastructure to provide these services would require the DOVA infrastructure operators to invest in the infrastructure and also require an agreement between the DOVA infrastructure operators and the ADS developers. There will be a need to create a governance structure for both the decision-making process on which ODD attribute information can be provided via infrastructure as well as the quality of the information.

It is also important to note that the while the attributes discussed in the tables of this chapter are ODD attributes from the viewpoint of the ADS, for the other stakeholders such as road operators, traffic managers, road works and winter maintenance contractors, and human drivers the attributes are simply local condition attributes describing the state of local conditions. Any local condition attribute may be important to one, some or all of the stakeholders. Thereby, any local condition attribute may be an ODD attribute to one, some, all or none of the ADS operating on the road in question.

2.3 Needs of automated driving systems

Information needs assessed as "high" according to the TM4CAD analysis for the automated driving systems (ADS) regarding *physical attributes of the roadway and its environs* include locations of road boundaries which indicate basic road features, drivable area boundaries in intersections, entrance and exit ramps. Similarly roadside landmarks to support localization referencing (road work or motorway type and location dependent), quality of pavement marking visibility, and road geometry constraints (e.g., curvature and grades) extend and add accuracy to the definition of the ADS drivable area. Information needs also concern safety critical information of road shoulder conditions on both sides (e.g., for Minimal Risk Manoeuvres), and notifications of locations with occluded visibility as well as limited load-bearing capacity of roadway and bridge structures, especially if these constrain the routing of heavy vehicles such as trucks.

Digital infrastructure support information needs considered high in the TM4CAD analysis for the ADS include variable message sign contents, locations of incidents, emergency vehicles, special events (e.g., sport event) and blocked or closed road. All these enhance ADS awareness, e.g., in low visibility and makes it easier to foresee and react to upcoming sites and events. Average traffic speed and density can be used for example for strategic route planning and for tactical speed choice. Information on digital infrastructure locations of short and long range V2I/I2V communications (ITS-G5, LTE-V2X, 4G or 5G) with uplink and downlink capacities, locations where GNSS coverage is or is not available can help to assess available service level on the route. Similarly, as in the physical attributes, highway shoulder location occupancy and dynamic traffic access changes (e.g., dependent on time of day) support ADS awareness for e.g., Minimal Risk Manoeuvre situations and route planning. Remote human support assistance or remote driving via wireless communications can aid the ADS in difficult conditions.

Dynamically varying ambient environmental information on local conditions have medium to high information needs in all attributes. Many of these information needs are safety critical, for example, information about wet or ice on pavement surface, friction, or snow/slush accumulation. Also, other weather-related attributes, and predicted significant changes of snow and rainfall rates and flooding as well as lighting conditions have high importance for the ADS. Wind speed range has high relevance for automated trucks.

Operational attributes of the roadway have high information needs for the ADS. Operational attributes include safety critical information such as obstacles or debris on road surface, traffic rules, temporary static signs, speed limit information and incident recovery events. Roadside objects that change their locations over time can be included in the point cloud maps localization.

The following paragraphs present a short example of automated vehicle information support for each of the three scenarios of traffic jam, adverse weather area and road works.

Use-case 1: When AV encounters traffic jam or its dissolving

If the location and the length of traffic jam are known from the past records, the traffic managers (or their systems) have already implemented road-side monitoring stations or subscribing to floating vehicle data to observe the traffic flow and provide necessary information to traffic management users, traffic information services, and also to automated vehicles. In this case, usually the end location of traffic jam is known with some accuracy and it is easy to supply the information to each automated vehicle.

Use-case 2: When AV encounters adverse weather

Bad weather is among the most critical situations for AVs due to the limited capabilities of their in-vehicle sensors. It is obvious that when the rainfall rates and wind speeds are very strong such as in the case of typhoon or hurricane, or fog is very dense, automated driving (or driving at all) is not possible. However, there are cases in which automated driving is possible with the help of information from the infrastructure and reducing the speed of AVs.

Various information related to weather such as wind speed and direction, visibility reduction in fog, ice on pavement surface, snow/slush accumulation on surface can be measured by roadside sensors. However, the driving behaviours of the automated vehicles may differ according to the ODD specific to each vehicle. For example, under certain amount of snow accumulation on road surface a truck, a 4WD SUV, and light weight car can have totally different driving behaviours and thereby the consequences of the value of their ODD attributes may be different even if their ODDs would have exactly the same attributes.

Use-case 3: When AV encounters road work zone

One of the most needed information for automated vehicles are the locations of road work zones, lane-specific speed limits, portions of carriageway occupied by the maintenance vehicles, etc. If the vehicles receive this information in good time, the ADS can select the most suitable lane in advance to avoid unnecessary conflict with the operations at the road work zone.

Issues can emerge in cases where the ADS does not have the ability to manoeuvre the vehicle through the road works zone due to the zone's complexity, missing road signs and markings, or the actual emergence of hazardous objects related to road works. In this case, the ADS is expected to transfer control to the driver or perform a Minimal Risk Manoeuvre.

2.4 Needs of traffic managers

Traffic managers, or more broadly defined traffic management centres (TMCs) and their operating systems (TMSs), were typically collecting information on their own. 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 connected and automated vehicle systems, and the close linkage between ODD and ISAD, new additional sources of data and information are becoming available. The primes of these are already supposed to be 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 currently not be an explicit need of TMCs to have access to the latter kind of information. 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. 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), 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 are likely related to dynamic inputs:

- Varying weather conditions (in the broadest sense)
- Varying lighting conditions
- Local traffic conditions
- Changes in road surface conditions

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

A more elaborate set of requirements for road operators/TMCs/TMSs is provided in Maerivoet et al. (2023).

2.5 Needs of road maintenance contractors

Road and highway maintenance private contractors are usually contracted by the road authority or operator unless the road authority or operator itself also carries the road maintenance operator role. In the scenarios presented in the following chapter, the maintenance contractor is responsible of day-to-day road maintenance, such as snow removal, or a specific road or highway section maintenance, i.e., road works.

Information provider's role often falls on road maintenance contractors as a part of the contractual liability to maintain, repair or build a part of the road network, or while completing the task, the contractor can have a direct impact on the physical and digital road infrastructure support and its environs as well as information provided. For example, a contractor with a road work ongoing is responsible of assembling road work warning signs, creating, and informing roadside boundaries and possible capacity limitations, i.e., reporting all maintenance actions ongoing. Therefore, often the contactor is the primary, even real-time, source of maintenance information. Information to be provided by the contractors such as road works maintenance status information (e.g., location, time, route) can be specified in the procurement contract with the public authority. Therefore, in addition to the private maintenance contractor, the road authority or operator has a substantial role in deciding on road maintenance status information distribution in the road network.

Information needs for the *road maintenance contractors with regard to physical attributes of the roadway and its environs* include local information of road surface damage (e.g., potholes) and locations with poor visibility due to blind intersections or vegetation; all of these being useful for maintenance operations and improving road safety.

Digital infrastructure support information needs for the contractor are variable message sign content, GNSS differential correction signals availability and location of communication networks in the maintenance area. For example, GNSS correction signals and communication networks can improve work quality and be used by the road maintenance vehicles for maintenance work data collection as well as driver support. Road safety in the road work area can be improved with incident, special event and safety hazard locations including emergency vehicle location and traffic flow information.

Dynamically varying ambient environmental information on local conditions provide important information of possible safety risks and thereby urgent maintenance needs in the road maintenance area. This information can include visibility, rain- and snowfall rates, predictions of significant weather changes and heavy flooding. Other less relevant information for maintenance contractors can be wind speed range, pavement conditions, e.g., wet, cold or snow/slush cumulation, and special lightning conditions as well as electromagnetic interference.

Operational attributes of the roadway include the highest information need cluster of local condition information for the road maintenance contractors. Temporary static signs and real-time lane specific speed limits as well as maintenance vehicles on the road and work zone information provide information to implement the contractual work. Availability of C-ITS services with information on incident recovery events and routing advisory information offer safe and efficient traffic flow for the road work area. Availability of new services such as real-time merging guidance or assistance at motorway interchanges or entrance ramps, and real-time digital traffic rules, enable new tools to benefit the maintenance contractors.

2.6 Information needs of use cases

The following Tables 2.2 – 2.5 summarise the information needs analysis described in the previous sub-chapters with side-by-side table comparison between the local conditions / ODD attributes, three scenarios and three actors. Table 2.1 provides instructions on how to read the tables analysis. The analysis was carried out according to the method explained in chapter 2.1.

The information needs importance was assessed in the tables according to three asterisk levels of low (*), medium (**) and high (***). If there was no need for information, a hyphen (-) is presented. If the information need was unknown, this is indicated with a text 'unknown'. Information needs that were considered high for all or most of the three actors in all the three scenarios, were underlined and bolded in the below tables.

Table 2.1. How to read the information needs tables:

Scenario	**Traffic Jam**			**Adverse weather area**			**Static/dynamic Road Work Zone**		
	Actor and information need			Actor and information need			Actor and information need		
Local condition / ODD attribute	Mainte-nance operator	Traffic manager	Auto-mated vehicle (ADS)	Mainte-nance operator	Traffic manager	Auto-mated vehicle (ADS)	Mainte-nance operator	Traffic manager	Auto-mated vehicle (ADS)
Attribute name	Evaluation of information need for each of the above actors and scenarios: Abbreviations: - none * low ** medium *** high								
Attribute name	<u>*******</u> <u>**High information needs for all or most of the actors in the scenarios is bolded and underlined**</u>								

Table 2.2. Information needs summary of <u>physical attributes of the roadway and its environs</u>. Local conditions / ODD attributes with high information need (***) for all or most of the three actors have been bolded and underlined. Abbreviations: MO = Maintenance Operator, WMO = Winter Maintenance Operator, RW = Road Works, TM = Traffic Manager, AV = Automated Vehicle, ADS = Automated Driving System

Scenario	**Traffic Jam**			**Adverse weather area**			**Static/dynamic RWZ**		
	Actor and information need			Actor and information need			Actor and information need		
Local condition / ODD attribute	MO	TM	AV (ADS)	MO or WMO	TM	AV (ADS)	RW or MO	TM	AV (ADS)
<u>Locations of road boundaries</u>	**<u>-</u>**	**<u>***</u>**	**<u>***</u>**	**<u>-</u>**	**<u>***</u>**	**<u>***</u>**	**<u>-</u>**	**<u>***</u>**	**<u>***</u>**
Geofence/ geographic area	**-**	*******	*******	**-**	*******	*******	**-**	*******	*******
Zone boundaries	-	***	*	-	***	*	-	***	***
Roadside landmarks	-	**	***	-	**	***	-	*	***
Special-purpose localization references	-	*	*	-	*	*	-	*	*
Quality of pavement marking visibility	**	*	***	**	*	***	**	*	***
Load-bearing capacity of roadway or bridge structures	-	***	***	-	-	-	-	***	***
Road surface damage	***	**	*	-	**	**	***	*	*
Game fence locations and condition	**	*	*	**	**	**	**	*	*
Vegetation obscuring sight angles or visibility of signs	***	*	**	***	*	**	***	*	**
Road geometry constraints	-	**	***	-	**	***	-	**	***
Road shoulder conditions on both sides	-	***	***	-	***	***	-	*	**
Notifications of locations with occluded visibility	-	*	***	-	*	***	-	*	***

Table 2.3. Information needs summary of digital infrastructure support. Local conditions / ODD attributes with high information need (***) for all or most of the three actors have been bolded and underlined. Abbreviations: MO = Maintenance Operator, WMO = Winter Maintenance Operator, RW = Road Works, TM = Traffic Manager, AV = Automated Vehicle, ADS = Automated Driving System

Scenario	**Traffic Jam**			**Adverse weather area**			**Static/dynamic Road Work Zone**		
	Actor and information need			Actor and information need			Actor and information need		
Local condition / ODD attribute	MO	TM	AV (ADS)	MO or WMO	TM	AV (ADS)	RW or MO	TM	AV (ADS)
Variable message sign contents	***	***	***	-	***	***	-	***	***
Locations where V2I/I2V communications are available	*	***	***	*	***	***	-	***	***
Locations where GNSS differential correction signals are available	-	*	***	***	*	***	*	*	***
Locations where GNSS coverage is NOT available now, by GNSS service	*	*	***	**	*	***	*	*	***
Electronic toll collection systems and their associated pricing	-	***	**	-	-	**	-	-	**
Locations of incidents that represent traffic impediments or safety hazards	***	***	***	***	***	***	***	***	***
Emergency vehicle locations and direction/speed of travel of each one	-	***	***	***	**	***	***	**	***
Current average traffic speed and density by lane and road section	*	***	***	***	***	***	***	***	***

Current percentage of heavy vehicles in traffic stream, by lane and road section	*	*	*	*	*	*	*	*	*
Special events creating abnormal traffic conditions and their locations	***	***	***	***	***	***	***	***	***
Temporarily blocked or closed road locations	***	***	***	***	***	***	***	***	***
Locations with high density of pedestrians	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.
Locations with high density of cyclists or users of micro-mobility devices	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.	Not relev.
Highway shoulder locations occupied by vehicles or debris	***	***	***	***	***	***	***	***	***
Locations with dynamic traffic access changes	***	***	***	***	***	***	***	***	***
Remote human support availability	**- or** ***	***	***	**- or** ***	***	***	**- or** ***	***	***

Table 2.4. Information needs summary of <u>dynamically varying ambient environmental conditions</u>. Local conditions / ODD attributes with high information need (***) for all or most of the three actors have been bolded and underlined. Abbreviations: MO = Maintenance Operator, WMO = Winter Maintenance Operator, RW = Road Works, TM = Traffic Manager, AV = Automated Vehicle, ADS = Automated Driving System

Scenario	**Traffic Jam**			**Adverse weather area**			**Static/dynamic Road Work Zone**		
	Actor and information need			Actor and information need			Actor and information need		
Local condition / ODD attribute	MO	TM	AV (ADS)	MO or WMO	TM	AV (ADS)	RW or MO	TM	AV (ADS)
Wind speed range	*	***	***	*	***	***	*	***	***
<u>Visibility range with rain/snow/sleet/hail in visible light spectrum</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
<u>Visibility range with rain/snow/sleet/hail in lidar infrared spectrum</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
<u>Rainfall rate in mm/hr</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
<u>Snowfall rate in qualitative ranges</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
<u>Visibility range with other particulate obscurants in visible light spectrum</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
<u>Visibility range with other particulate obscurants in lidar infrared spectrum</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
<u>Predicted significant changes in key weather attributes</u>	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**	**<u>***</u>**
Qualitative ambient lighting conditions	-	*	**	-	*	**	-	*	**
Quantitative ambient lighting conditions	-	*	***	-	*	***	-	*	***

Special challenging lighting conditions	*	**	***	*	**	***	*	**	***
Electromagnetic interference	**	***	***	**	***	***	*	***	***
Wet pavement surface	***	***	***	***	***	***	*	***	***
Ice on pavement surface	***	***	***	***	***	***	*	***	***
Cold pavement surface (potential for ice if wet)	***	***	***	***	***	***	*	***	***
Road surface friction	***	***	***	***	***	***	*	***	***
Light to moderate snow/slush accumulation on surface	***	***	***	***	***	***	*	***	***
Heavy snow/slush accumulation on surface	***	***	***	***	***	***	*	***	***
Light to moderate flooding (puddles) on surface	***	***	***	***	***	***	*	***	***
Heavy flooding – potentially impassible to low-profile vehicles	***	***	***	***	***	***	***	***	***

Table 2.5. Information needs summary of operational attributes of the roadway. Local conditions / ODD attributes with high information need (***) for all or most of the three actors have been bolded and underlined. Abbreviations: MO = Maintenance Operator, WMO = Winter Maintenance Operator, RW = Road Works, TM = Traffic Manager, AV = Automated Vehicle, ADS = Automated Driving System

Scenario	**Traffic Jam**			**Adverse weather area**			**Static/dynamic Road Work Zone**		
	Actor and information need			Actor and information need			Actor and information need		
Local condition / ODD attribute	MO	TM	AV (ADS)	MO or WMO	TM	AV (ADS)	RW or MO	TM	AV (ADS)
Temporary static signs	***	***	***	***	***	***	***	***	***
Maintenance vehicles using portions of carriageway	***	***	***	***	***	***	***	***	***
Work zones	***	***	***	***	***	***	***	***	***
Incident recovery events (crash scenes, crime scenes, dropped loads, landslides, avalanches…)	***	***	***	***	***	***	***	***	***
Availability of specific C-ITS information services	-	***	***	-	***	***	-	***	***
Availability of real-time merging guidance or assistance at motorway interchanges or entrance ramps	-	***	***	-	***	***	-	***	***
Real-time lane-specific speed limit info availability at specific locations.	*	***	***	*	***	***	*	***	***
Obstacles or debris on road surface	***	***	***	***	***	***	***	***	***
Roadside objects that change their locations over time, such as parked vehicles or trash cans	*	*	***	*	*	***	*	*	***
Routing advisory information	-	***	***	-	***	***	-	***	***
Traffic rules and regulations in digital form, updated in real time	-	***	***	-	***	***	-	***	***

3 Prioritisation of information needs

3.1 Method of prioritisation

Local condition / ODD attribute information priority for the three actors of roadworks and maintenance operator, traffic manager and automated vehicle (automated driving system) developer or operator was assessed based on the three criteria described below.

First, information needs importance which was extracted from the three scenarios of traffic jam, adverse weather area and static/dynamic roadworks zone evaluated in the previous chapter of “Information Needs”. Total sum of the three scenarios information needs from low to high was calculated and then an average was calculated. This average was qualitatively analysed to avoid any bias between the scenarios.

Secondly, safety criticality of the information assessed looking at a situation where the information would not be available and its impact to the actor. Safety was evaluated in four levels: no safety impact (-), low (*), medium (**) and high (***).

Thirdly, additional work and costs for the actor compared to regular operations if providing the status information. Costs occurrence have been evaluated by the TM4CAD based on the following criteria: 1) Information is needed by the actor, 2) Information is not easily available today and 3) Information is not provisioned by other stakeholders. If the previously mentioned criteria apply to the actor, then work and costs are evaluated in range of low (+), medium (++) or high (++). Also, if an actor has a possibility for cost savings by producing the information or increasing the information quality by itself, this has been marked as a cost savings (-).

The cost savings for an actor can be a result of an increase of costs for another actor. A basic issue is that all of the actors have a role as a user of the information but also as a producer of the information. For instance, the roadworks operator is a key information provider for the roadworks zones while also utilising the exact digital information of the roadworks in improving the efficiency of the roadworks related processes.

An additional evaluation criterion not included was the time criticality, i.e., urgency of information delivery presented in the TM4CAD deliverable 2.1. Time criticality was considered having a low impact for the overall priority and as it’s also included in the next chapter’s evaluation of information quality.

Next, an overall assessment was completed by a qualitative comparison among the three actors’ information priorities. The comparison considered the differences among the actors, i.e., whether an actor has a much lower priority compared to the other actors.

Finally, the priority assessments were validated in a survey targeting vehicle manufacturers and in two workshops, one oriented towards vehicle manufacturers and the other towards road authorities via CEDR’s CAD Working Group. The vehicle manufacturer survey was sent via the Hi-Drive consortium (Hi-Drive 2022) involving all major vehicle manufacturers and automated driving system developers in Europe. As the consortium is research oriented, the views do not represent the views of the strategic decision makers of the vehicle manufacturers. However, they likely do represent the views of the ADS developers for the automated driving use cases that we are discussing in TM4CAD.

3.2 Automated driving system provider/operator priorities

The importance needs concerning the *physical attributes of the roadway and its environs* local condition / ODD attribute information have a large variety. According to the analysis, the basic road features of boundaries, landmarks, pavement marking quality, geometry, and road shoulder conditions together with occluded visibility locations had a high level of importance, while other physical attributes had low or medium. Although quality of pavement marking has a high importance now, this might change in future. When compared to the second criterion, safety criticality, the importance mostly follows the information need. Exceptions are zone boundaries, load-bearing capacity, and road surface damage, which have a high safety criticality rating but were not considered extremely important. Load-bearing capacity's criticality concerns mostly heavy trucks, and less of cars. Thirdly, additional work and costs for the AV industry were mostly considered non-existent, but attributes of quality of pavement marking and road surface damage may cause an exception as ADS could detect and report information of those attributes. The provision of such information could cause additional costs for the AV fleet operators but lower the costs of the maintenance operators and road operators even more than the additional costs for the AVs.

Digital infrastructure support local condition / ODD attribute information needs importance was high for most of the attributes (12/16). Safety criticality was mostly following the priority of the information needs. Highest overall priorities included variable message signs contents, location of V2I communication and GNSS signals and coverage, incident and emergency vehicles, special events, closed or blocked road as well as highway shoulder locations and remote human support. The remote assistance importance was also the costliest to implement, if required. Moderate costs could occur with incident locations, current average traffic speed and other digital information of changing traffic conditions. Similarly, as previously, ADS detection and reporting capabilities of these information could benefit not only the ADS developer and OEMs, but other stakeholders and actors, depending on the need and update frequency of the information. Also, V2I communications availability could be collected by the AV, depending on the need of stakeholders.

Dynamically varying ambient environmental conditions local condition / ODD attribute information needs importance was considered high for all the attributes except one: qualitative ambient lightning conditions being medium. Similarly, safety criticality of the information followed the information need priority except for the attribute predicted significant changes in key weather attributes, which was considered medium. Wind speed range was considered important mostly for heavy trucks. Small additional work and costs could occur for several of the attributes, if they are required in operation. Road surface friction and other similar road surface condition measures could also be detected and reported, if possible, with cost implications.

Operational attributes of the roadway local condition / ODD information needs importance was regarded high for all of the attributes. Safety criticality was high in most of the attributes, except for roadside objects location changes (medium) and routing advisory information (low). Additional work and costs could occur for the attributes of incident recovery events, obstacles or debris on road and roadside objects that change, if the detection and reporting of these information has cost consequences. Also, the availability of specific C-ITS information services could cause costs, as some actor must collect the information of their availability and then provide that.

3.3 Traffic management priorities

Before considering the prioritisation for traffic managers, it is necessary to make a crucial assumption. The underlying idea is that many of a road's attributes are in general by default available to the road operators who (either directly or indirectly) are responsible for road construction and maintenance. As such, we assume that these same attributes are logically made available to traffic management centres (if they did not have them already). Think for example of road curvatures, pavement types, infrastructural installations (such as variable message signs and others), etc. We assume their locations and other characteristics (i.e. the sets of attributes) are known by the road operators, and this information can be relayed in a straightforward manner to the traffic management centres. This kind of interaction has also the advantage that any attributes denoting the same (infrastructural) element are automatically harmonised between the different road network operation actors.

The result of this, is that most of the additional work and costs become rather limited for traffic management centres, especially in relation to typical physical infrastructural elements such as zone boundaries, roadside landmarks, game fence locations, road geometry constraints, etc. This is also reflected in the table where these attributes are classified as only requiring low work/cost efforts. In some cases, the information is not so readily available, and more of a dynamic nature, requiring more work/cost. An example of the latter are the detection of infrastructural damage such as potholes, vegetation obscuring visibility, etc. In such cases, connected and automated vehicles can become an important information source. Regarding the safety criticality aspects, the most relevant ones – for traffic managers – are attributes such as infrastructural load-bearing capacities, road conditions, and road characteristics (including curvatures and the like).

When looking at the digital infrastructural elements, we note that the safety criticality for traffic management centres is more related to incident locations, detailed average traffic speeds and densities, lane blockages, etc. These attributes typically share, in this case, the common characteristic of being dynamically changing. Considering the additional work/cost, we note that these are higher for traffic management centres in the case of V2X roll-out locations, as well as incident locations and those attributes mentioned for safety criticality. Here again, we note that them being highly dynamic in nature contributes to the extra work/cost required to collect them but this can be assisted by the connected and automated vehicles as an information source.

3.4 Road maintenance contractor priorities

Physical attributes of the roadway and its environs local condition / ODD attribute information importance for the maintenance operator was evaluated mostly as 'no information need' in the three scenarios of traffic jam, adverse weather area and static/dynamic road work zone. Only road surface damage (e.g., potholes) and vegetation obscuring sight angles were considered having a medium information need for the contractor. On the other hand, the second evaluation point of safety criticality of the information was evaluated to the highest level in most of the local condition cases (eight out of twelve), for example road boundaries, landmarks as well as quality and conditional attributes. Thirdly, additional work and costs for the maintenance operator occur if quality requirements of the information are increased, for example by the road authority through a contractual agreement. Additional work and costs would also increase if the operator had to provide more accurate information about locations of road or zone boundaries than done today. On the other hand, the information from aVs could also contribute and thereby mitigate the cost increase.

Digital infrastructure support local condition / ODD attribute information needs importance was evaluated being high for locations of incidents, special events creating abnormal traffic conditions, temporarily blocked or closed road, highway shoulders and dynamic traffic access changes. Remote human support is dependent whether the support is required for maintenance vehicle (high) or other vehicles (none). Secondly, safety criticality was considered medium or high on all the local conditions, similarly also the information need was high. One exception with variable message sign (VMS) contents where the information need is low, but safety criticality is high. This means that in the case of absence of the VMS information, it could cause safety concerns for the operator for example in high speed motorway sections. Thirdly, additional work and costs do not occur, or they are low since most of the information is easily available and provided by other stakeholders. An exception occurs at locations where V2I/I2V communications are available as for example C-ITS installations and roadworks-related service provision could cause high costs for the operator.

Dynamically varying ambient environmental conditions local condition / ODD attribute information needs importance for the maintenance operator was overall from medium to high. Only qualitative and quantitative ambient lighting conditions were considered having no information needs as well as wind speed range and special challenging lightning conditions having low information needs. Secondly, the safety criticality followed in most parts the information needs' importance level, with exceptions on ice on pavement, light to moderate and heavy snow/slush accumulation on surface as well as light to moderate flooding on surface, where the safety criticality was considered higher (***) than the actual information need (**) of the operator. Thirdly, pavement surface ice and snow/slush or flooding information can provide possible cost savings for the operator, as more accurate location and timely information could increase efficiency of the maintenance, e.g., for a winter service vehicle carrying out snow removal. Otherwise, dynamic information availability was considered good and therefore costs would not occur. Only exception being electromagnetic interference, which could add low costs for the operator.

Operational attributes of the roadway local condition / ODD attribute information needs importance was high for all attributes except one: roadside objects that change their locations over time. Roadside objects with chancing locations are more common in city environment, but mostly rare in motorway areas, as described in the previous chapter's analysis. Secondly, safety criticality in most parts followed the information needs importance being medium or high. Thirdly highest work and costs for the operator would occur if availability of specific C-ITS information services would need to be provided. Also, medium costs would occur for maintenance vehicle and work zone information provision. Possible costs savings could be possible for obstacles or debris and roadside objects information as this could increase the efficiency in terms of timing and planning of the operator's work.

3.5 Overall priorities and limitations

Tables 3.1 – 3.5 summarise and present the overall local condition / ODD attribute priority levels described above with side-by-side table comparisons across the three scenarios and actors.

Table 3-1. How to read the overall priority tables.

Description of the table rows and columns	Actor name Total of three actors: roadworks or maintenance operator, traffic manager and automated vehicle (automated driving systems) developer Priority evaluation criteria for the three scenarios: Traffic Jam, Adverse weather area and static/dynamic roadworks zone			Overall priority level
Local condition / ODD attribute	Information needs importance in the three scenarios for the actor*	Safety criticality	Additional work and costs for the actor (compared to regular operations)	Summary of the three actors' priority evaluation criteria
Name and description of the local condition / ODD attribute presented originally in the TM4CAD Deliverable 2.1	Actor's information needs importance extracted from the chapter 2.5 three scenarios of traffic jam, adverse weather, and static/dynamic road work zone Abbreviations: - no impact * low ** medium *** high	Information safety criticality: If the information would not be available, what would be the impact? Abbreviations: - no impact * low ** medium *** high	Work and costs occur for the actor IF following conditions apply, and the actor will need to provide the information by itself: 1) Information is needed by the actor 2) Information is not easily available today 3) Information is not provisioned by other stakeholders Abbreviations: possible cost savings 0 no costs + low costs ++ medium costs +++ high costs	**Level of priority for all the actors in the three scenarios: HIGH, MEDIUM, or LOW**

Table 3-2. Overall priority level of <u>physical attributes of the roadway and its environs</u>.

Actor	Roadworks or Maintenance Operator			Traffic Manager			Automated Vehicle (Automated Driving System) developer			Overall priority level
	Priority evaluation criteria			Priority evaluation criteria			Priority evaluation criteria			
Local condition / ODD attribute	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Priority
Locations of road boundaries	-	***	+++	***	**	+	***	***	0	**HIGH**
Geofence/ geographic area	-	*	+	***	**	+	***	***	0	**HIGH**
Zone boundaries	-	**	+++	***	**	+	**	***	0	**HIGH**
Roadside landmarks	-	***	+	**	*	++	***	***	0	**HIGH**
Special-purpose localization references	-	-	+++	*	*	+	*	*	0	**LOW**
Quality of pave-ment marking visibility	**	***	+++	*	**	++	***	***	+	**HIGH**
Load-bearing capacity of roadway or bridge structures	-	***	0	**	***	+	**	***	0	**MEDIUM**
Road surface damage	**	***	++	**	*	+++	**	***	+	**MEDIUM**
Game fence locations and condition	**	**	++	*	*	+	*	**	0	**LOW**
Vegetation obscuring sight angles or visibility of signs	***	**	++	*	**	+++	**	**	0	**MEDIUM**
Road geometry constraints	-	*	0	**	***	+	***	***	0	**HIGH**
Road shoulder conditions on both sides	-	***	0	**	***	+	***	***	0	**HIGH**
Notifications of locations with occluded visibility	-	***	0	*	**	++	***	***	0	**HIGH**

Table 3-3. Overall priority level of __digital infrastructure support__.

Actor	**Roadworks or Maintenance Operator**			**Traffic Manager**			**Automated Vehicle (Automated Driving System) developer**			**Overall priority level**
	Priority evaluation criteria			**Priority evaluation criteria**			**Priority evaluation criteria**			
Local condition / ODD attribute	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Priority
Variable message sign contents	*	***	+	***	**	++	***	***	0	**HIGH**
Locations where V2I/I2V communications are available	*	*	+++	***	***	+++	***	**	+	**HIGH**
Locations where GNSS differential correction signals are available	*	**	+	*	*	+	***	***	+	**MEDIUM**
Locations where GNSS coverage is NOT available now, by GNSS service	*	**	0	*	*	+	***	***	+	**MEDIUM**
Electronic toll collection systems and their associated pricing	-	-	0	*	*	+	**	-	0	**LOW**
Locations of incidents that represent traffic impediments or safety hazards	***	***	+	***	***	+++	***	***	+	**HIGH**
Emergency vehicle locations and direction/speed of travel of each one	**	**	0	**	**	++	***	***	0	**MEDIUM**

Current average traffic speed and density by lane and road section	**	*	0	***	***	+++	***	**	+	**HIGH**
Current percentage of heavy vehicles in traffic stream, by lane and road section	*	*	0	*	*	+++	*	**	0	**LOW**
Special events creating abnormal traffic conditions and their locations	***	***	+	***	*	+++	***	**	+	**HIGH**
Temporarily blocked or closed road locations	***	***	+	***	***	++	***	***	+	**HIGH**
Locations with high density of pedestrians	-	*	0	Not relevant	Not relevant	Not relevant	-	-	0	**LOW**
Locations with high density of cyclists or users of micro-mobility devices	-	*	0	Not relevant	Not relevant	Not relevant	-	-	0	**LOW**
Highway shoulder locations occupied by vehicles or debris	***	***	+	***	***	+++	***	***	+	**HIGH**
Locations with dynamic traffic access changes	***	**	0	***	***	++	***	**	0	**HIGH**
Remote human support	Depend (***) or (-)	Depend (***) or (-)	Depend (***) or (-)	***	***	+++	***	***	+++	**HIGH**

Table 3-4.Overall priority level of <u>dynamically varying ambient environmental conditions</u>.

Actor	Roadworks or Maintenance Operator			Traffic Manager			Automated Vehicle (Automated Driving System) developer			Overall priority level
	Priority evaluation criteria			Priority evaluation criteria			Priority evaluation criteria			
Local condition / ODD attribute	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Priority
Wind speed range	*	*	0	***	**	+++	***	***	0	**MEDIUM**
Visibility range with rain/snow/sleet/hail in visible light spectrum	***	***	0	***	***	+++	***	***	+	**HIGH**
Visibility range with rain/snow/sleet/hail in lidar infrared spectrum	***	***	0	***	**	+++	***	***	+	**HIGH**
Rainfall rate in mm/hr	***	***	0	***	**	+	***	***	+	**HIGH**
Snowfall rate in qualitative ranges	***	***	Possible cost savings	***	**	++	***	***	+	**HIGH**
Visibility range with other particulate obscurants in visible light spectrum	***	***	0	***	***	+++	***	***	+	**HIGH**
Visibility range with other particulate obscurants in lidar infrared spectrum	***	***	0	***	***	+++	***	***	+	**HIGH**
Predicted significant changes in key weather attributes	***	***	Possible cost savings	***	**	+++	***	**	0	**HIGH**
Qualitative ambient lighting conditions	-	-	0	**	*	++	**	***	0	**LOW**
Quantitative ambient lighting conditions	-	-	0	***	*	+++	***	***	0	**MEDIUM**
Special challenging lighting conditions	*	*	0	***	**	+++	***	***	+	**MEDIUM**

Electromagnetic interference	**	**	+	***	***	+++	***	***	+	**HIGH**
Wet pavement surface	**	**	0	***	***	+++	***	***	+	**HIGH**
Ice on pavement surface	**	***	Possible cost savings	***	***	+++	***	***	+	**HIGH**
Cold pavement surface (potential for ice if wet)	**	**	Possible cost savings	***	**	+++	***	***	+	**HIGH**
Road surface friction	**	**	Possible cost savings	***	**	+++	***	***	+	**HIGH**
Light to moderate snow/slush accumulation on surface	**	***	Possible cost savings	***	**	++	***	***	+	**HIGH**
Heavy snow/slush accumulation on surface	**	***	Possible cost savings	***	***	++	***	***	+	**HIGH**
Light to moderate flooding (puddles) on surface	**	***	Possible cost savings	***	*	+++	***	***	+	**HIGH**
Heavy flooding – potentially impassible to low-profile vehicles	***	***	Possible cost savings	***	***	++	***	***	+	**HIGH**

Table 3-5. Overall priority level of <u>operational attributes of the roadway</u>.

Actor	Roadworks or Maintenance Operator			Traffic Manager			Automated Vehicle (Automated Driving System) developer			Overall priority level
	Priority evaluation criteria			Priority evaluation criteria			Priority evaluation criteria			
Local condition / ODD attribute	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Inform. need import.	Safety critical	Addit. work and cost	Priority
Temporary static signs	***	***	+	***	**	+	***	***	0	**HIGH**
Maintenance vehicles using portions of carriageway	***	***	++	***	*	+	***	***	0	**HIGH**
Work zones	***	***	++	***	**	+	***	***	0	**HIGH**
Incident recovery events (crash scenes, crime scenes, dropped loads, landslides, avalanches…)	***	***	+	***	**	++	***	***	+	**HIGH**
Availability of specific C-ITS information services	***	**	+++	***	**	+++	***	***	+	**HIGH**
Availability of real-time merging guidance or assistance at motorway interchanges or entrance ramps	***	**	0	***	**	+++	***	***	0	**HIGH**

Real-time lane-specific speed limit information availability at specific locations.	***	***	0	***	**	+	***	***	0	**HIGH**
Obstacles or debris on road surface	***	***	Possible cost savings	***	***	+++	***	***	+	**HIGH**
Roadside objects that change their locations over time, such as parked vehicles or trash cans	*	-	Possible cost savings	*	**	+++	***	**	+	**MEDIUM**
Routing advisory information	***	**	0	***	*	+	***	*	0	**MEDIUM**
Traffic rules and regulations in digital form, updated in real time	***	**	+	***	**	+++	***	***	0	**HIGH**

3.6 Validation of the overall priorities and limitations

The automated driving system developers' priorities and limitations were assessed with two methods as explained in the method chapter. First, the preceding chapter presented the TM4CAD project members' evaluation of the information priorities for the three scenarios and actors. Second, to validate the TM4CAD analysis this chapter presents the results of the survey and workshop targeting the ADS system developers.

A pre-workshop online survey was conducted for the developers, resulting in 8 responses. The aim of the survey was to validate the TM4CAD analysis of the information priorities. The survey asked whether the developer representative agrees or disagrees with the TM4CAD prioritisation of each of the ODD attributes in the four clusters. If the developer would disagree, it was requested to specify whether the attribute should have, on average, a low, medium, or high priority. No response would indicate agreement with the TM4CAD analysis. After each of the four clusters, also an open field response option was provided to further elaborate the answer.

The survey results present mostly good agreement with the TM4CAD estimates as always at least half of the respondents were in full agreement. Both the TM4CAD analysis and developers' feedback indicated high priority in general for most of the ODD attributes.

Some of the open field written answers highlighted urban use case examples, meanwhile the TM4CAD analysis scope was oriented only to highway and motorway use cases. Also, for some answers the role of the road operator was also considered when estimating the information priority. Several written answers referred to difficulties and cost for providing each of the individual ODD attribute information.

Individual variety in the responses included one respondent with more than 90 % of the attribute's priority level being low. This could reflect feedback given in the written comments and workshop discussion stating that the infrastructure provided information quality cannot be guaranteed to be trusted in all the attribute cases, and therefore the priority of the information should be considered lower when provided by the infrastructure. The use of external information requires not only trustworthiness of data both in terms of correctness and cybersecurity but also solving of any liability issues. For example, if external information contributes to a crash of the vehicle in automated mode, the responsibility still resides with the ADS developer. Therefore, infrastructure information quality has high importance, and possible backup and redundancy of the infrastructure information monitoring would be required. If the information would come from inside the vehicle sensor range, it could be used for redundancy. On the other hand, information coming from outside of the vehicle's sensor range could be used to extend the geographical area of the ODD if the ADS is convinced of the veracity and reliability of the information.

Remote human support ODD attribute (such as remote supervision of the automated vehicle), which was evaluated being high priority information in the TM4CAD analysis, was considered low priority by half of the developers in the survey. Written and workshop feedback indicates that remote human support was partly considered being a more distant future service. Other attributes that had slight deviation were GNSS coverage unavailability, wind speed range, special challenging lightning conditions, wet pavement surface and road surface friction. The dynamic nature of weather conditions and possible variations in measuring these conditions such as the pavement friction and wet conditions refers to the previously mentioned trust issues with the information. In addition, sudden wind speed changes can be very local and therefore changing in different parts of road sections as indicated in some of the comments and discussions. Landmarks and GNSS positioning on the other hand would require highly accurate digital maps to provide benefits.

Quality of pavement marking visibility was raised as an example by both the ADS developers and road authorities on how the ADS development is a constantly changing dynamic domain. Although pavement marking visibility has high priority in the TM4CAD analysis and had support in the survey and workshops, there are indications from vehicle manufacturers that higher quality pavement markings than used today would not be a necessary requirement for the ADS to operate. Today and in the future, the road markings serve also the needs of drivers of SAE Level 0-2 vehicles. Therefore, pavement marking maintenance costs are justified and acceptable.

There was also a discussion at the CEDR workshop whether it would be possible to assess the future need and importance of the attribute information as done for a few attributes by an Australian study (Irannezhad et al, 2022). We concluded that it would be very difficult to assess the importance and need of the ODD attributes in the long term for the wide range of the attributes and likely this would end in very uncertain results. The best indication of the future development can be gathered from the latest development projects such as the Hi-Drive project addressing the key challenges currently hindering the progress of developments in vehicle automation and ODD continuity.

4 Data and information quality

4.1 Quality indicators

The European ITS Platform projects EIP, EIP+ and EU EIP have developed quality requirements for traffic information. The quality criteria specified in that work are presented in Table 4-1.

Table 4-1. Quality criteria for Real-Time Traffic Information RTTI and Safety-Related Traffic Information SRTI from EU EIP (Kulmala et al 2019).

	Definition of Quality Criteria for RTTI and SRTI		Applicable for: Event Information	Applicable for: Status-Oriented Information
Level of Service	**Geographical coverage**	Percentage of the road network covered by the (content provision) service	X	X
Level of Service	**Availability**	Percentage of the time the (content provision) service is available	X	X
Level of Quality	**Timeliness (start)**	The time between the occurrence of an event and the acceptance* of the event	X	-
Level of Quality	**Reporting period**	The time interval for refreshing / updating the status reports	-	X
Level of Quality	**Timeliness (update)**	The time between the end or (safety) relevant change of condition and the acceptance* of this change	X	-
Level of Quality	**Timeliness (update)**	The average age of the sensor data used in the most recent reporting period	-	X
Level of Quality	**Latency (content side)**	The time between the acceptance of the event or its end or (safety) relevant change of condition and the moment the information is provided by the content access point	X	-
Level of Quality	**Latency (content side)**	The time between the calculation of the reporting data and the moment the information is provided by the content access point	-	X
Level of Quality	**Location accuracy**	The relative accuracy of the referenced location with respect to the actual location of the actual event	X	-
Level of Quality	**Reporting accuracy**	The relative accuracy of the reported quantity (speed or travel time) versus the actual value (average experience of road users in a given reporting period)	-	X
Level of Quality	**Classification correctness**	100% - percentage of the published events which are known to be not correct (concerning actual occurrence of this event type / class), and which result in a consequence for the user behaviour	X	-
Level of Quality	**Error Rate**	Percentage of published status reports which fall below a minimum accuracy	-	X
Level of Quality	**Event coverage**	Percentage of the events which are known to be correctly detected and published by type / class, time and location (i.e. detection rate)	X	-
Level of Quality	**Report coverage**	The percentage of reporting locations for which a status report is received in any given reporting period	-	X

* Acceptance here means acceptance by the operator at the operational entity such as a traffic management centre who then decides to publish the information

The C-ITS quality package from EU EIP (Lubrich et al. 2022) changes the Reporting period indicator to Refreshment rate defined as “Time interval for refreshing / updating the status reports coming from a data sender.”.

The Finnish Transport Infrastructure Agency has in its report (FTIA 2022) on dynamic traffic management and monitoring systems added the indicators in Table 4-2 to those of EU EIP.

Table 4-2. Additional quality criteria to those from EU EIP (FTIA 2022).

Quality indicator	Definition of indicator
Monitoring point density	Minimum density of monitoring stations on road section or maximum link length for link-related data in operating environment
Coverage of data types	Data or sensor types required in the operating environment
Measurement accuracy	Minimum accuracy for displaying data monitored
Performance conditions	The conditions in which the system operation and performance is guaranteed
Data transfer delay	The time from transmission of data from monitoring station to the receipt of data at server

Table 4-3 shows the compiled quality criteria candidates for Distributed ODD attribute Value Awareness framework and data exchanged within it.

Table 4-3. Proposed quality criteria for the Distributed ODD attribute Value Awareness framework and the data exchanged in it.

Definition of Quality Criteria for Distributed ODD Attribute Value Awareness Framework		Applicable for: Event Information	Status-Oriented Information	DOVA frame-work
Geographical coverage	Percentage of the road network or link covered by the (content provision) service	-	-	X
Availability	Percentage of the time the (content provision) service is available	-	-	X
Performance conditions	The conditions in which the system operation and performance is guaranteed	-	-	X
Coverage of data types	Data or sensor types required	-	-	X
Timeliness (start)	The time between the occurrence of an event and the acceptance* of the event	X	-	
Refreshment rate	Time interval for refreshing / updating the status reports coming from a data sender	-	X	
Data transfer delay	The time from transmission of data from monitoring station to the receipt of data at server	X	X	
Timeliness (update)	The time between the end or (safety) relevant change of condition and the acceptance* of this change	X	-	
	The average age of the sensor data used in the most recent reporting period	X	X	
Latency (content side)	The time between the acceptance of the event or its end or (safety) relevant change of condition and the moment the information is provided by the content access point	X	-	
	The time between the calculation of the reporting data and the moment the information is provided by the content access point	-	X	
Location accuracy	The relative accuracy of the referenced location with respect to the actual location of the actual event	X	X	
Monitoring point density	Minimum density of monitoring stations on road section or maximum link length for link-related data in operating environment	X	X	
Measurement accuracy	Minimum accuracy for displaying data monitored	-	X	
Reporting accuracy	The relative accuracy of the reported quantity (speed or travel time) versus the actual value (average experience of road users in a given reporting period)	-	X	
Error Rate	Percentage of published status reports which fall below a minimum accuracy	-	X	
Classification correctness (non-false positives)	100% - percentage of the published events which are known to be not correct (concerning actual occurrence of this event type / class), and which result in a consequence for the user behaviour	X	-	
Event coverage (true positives)	Percentage of the events which are known to be correctly detected and published by type / class, time and location (i.e. detection rate)	X	-	
Missed events (false negatives)	Percentage of occurred events that were not published (and perhaps not even detected)	X		
Report coverage	The percentage of reporting locations for which a status report is received in any given reporting period	-	X	

* Acceptance here means acceptance by the operator at the operational entity such as a traffic management centre who then decides to publish the information

4.2 Quality needs of use cases

The quality needs of the selected use cases are compiled in Table 4-4 and discussed below. The use cases have similar quality needs in many respects, but also some specific differences.

The geographical coverage goal needs to be 100% on all of the road network that the road operator is claiming to cover (i.e. any gaps and sections not covered need to be unambiguously listed by the road operator). Concerning road works, the target should be the coverage of the whole highway network. For the adverse weather and traffic jam use cases, the coverage should focus on the parts of the network where the respective problems are relevant.

The availability of the services needs to be as close to 100% as practically possible. A 99.9% availability means that the service is not available 9 hours in a year, which can likely be reached for the DOVA framework's various components but requires redundant solutions.

The roadside systems need to be able to operate in challenging ambient environment conditions in all temperatures that are likely to be experienced.

The data types to be covered in the different use cases vary a lot as the critical local conditions with regard to the ODD differ. For traffic jams the important local condition attributes are the traffic flow speed and occupancy. For the adverse weather use case, the attributes related to visibility, precipitation intensity and state of matter, road surface condition, wind (gust) speed, and friction are the ones to cover. In the road works use case, the exact location, status, local traffic management arrangement, lane availability, detour, and trajectory information are essential data types.

For the timeliness indicators (start of event or change in condition) the aim is to have immediate information. The information refresh rate should be as quick as possible and the data transfer delay in milliseconds. The latency of provision of information via the C-ITS service needs to be almost immediate with automated triggering. The provision of such data to be accessible via the National Access Point NAP should also be done quickly, e.g. within one minute.

The location accuracy is a challenge for current road network monitoring systems, where usually the knowledge of the road section or link between major intersections in question has traditionally been enough for many road information services. Even advanced motorway control systems have monitoring systems at 500-1000 m densities. An accuracy of 100 m or less can only be achieved by having the connected and automated vehicles as information providers. With regard to road works very accurate locations can be achieved by the road works contractors equipping the sites or in the case of mobile road equipment works the vehicles with accurately positioned C-ITS stations and using accurately positioned road equipment for local traffic management.

As described above the monitoring point density is often on the link level with 500 m density used in congestion prone sections. With regard to adverse weather, the monitoring stations are usually located at spots where the micro-climate deviates from that on other parts of the networks. Examples are bridges more prone to ice and frost formation, valleys more prone to fog banks, and long bridges affected by strong crosswinds. The road works use case is more simple as the road work site's both ends or the specific vehicles act as the monitoring points.

The measurement accuracy or the accuracy in which the digital information is provided to the user is highly dependent on the local condition attribute and could change in time according to technology evolution.

The quality levels for reporting accuracy, error rate, classification correctness (non-false positives), event coverage (true positives), missed events (false negatives), and report coverage should be as high as possible.

Table 4-4. Tentative quality needs of the use cases for the Distributed ODD attribute Value Awareness framework.

Quality Criteria for Distributed ODD attribute Value Awareness Framework	Traffic jam dissolving	Adverse weather	Road works
Geographical coverage	100 % on designated motorways with high traffic volumes	100% on designated highways with frequent weather issues	100% on highways
Availability	99.9%	99.9%	99.9%
Performance conditions	-50…+60°C	-50…+60°C	-50…+60°C
Coverage of data types	traffic flow speed, occupancy	visibility, precipitation intensity and state of matter, road surface condition, wind (gust) speed, friction	location, status, local traffic management, lane availability, detour, trajectory
Timeliness (start)	immediately		
Refreshment rate	as soon as possible		
Data transfer delay	< 10 ms		
Timeliness (update)	as soon as possible		
Latency (content side)	immediately (automated warning) <1 min (NAP)		
Location accuracy	<100 m	< 100 m	< 10 cm (trajectory) … < 10 m (others)
Monitoring point density	each link between major intersections, < 200 m on "hot" links	each critical micro climate spot	start and end of road works
Measurement accuracy	depends on indicator		
Reporting accuracy	as correct as possible		
Error Rate	as low as possible		
Classification correctness (non-false positives)	as high as possible		
Event coverage (true positives)	as high as possible		
Missed events (false negatives)	as low as possible		
Report coverage	as high as possible		

4.3 Quality recommendations

The quality recommendations are targeting a future situation when there would be sufficient numbers of connected and automated (SAE Level 4) vehicles operating on the road to provide reasonable quality floating vehicle data to provide accurate enough estimates of local road and traffic conditions. Thereby the quality recommendations do not apply to the situation today but rather around 2035. They also may seem too ambitious for some NRAs / Road Operators, but it remains to be seen whether this is actually the case or not.

The recommendations mostly focus on the quality of the information content as well as the service levels in time and road network coverage. On top of the quality digital information itself, the main ingredients for the implementation of the DOVA are secure and trustful information as well as reliable information. The security and trust can be verified by a certificate of the European C-ITS Security Credential Management System. The reliability can be verified as a safety qualifier in terms of meeting functional safety requirements (Erdem 2021).

This chapter builds on the quality levels currently accepted or proposed by European road operators for C-ITS services (Lubrich et al. 2022) while also considering the quality levels agreed by European road operators on safety-related and real-time traffic information services (Kulmala et al. 2019). With regard to automated driving, the recommendations utilise the finding of PIARC's Smart Roads Classifications by Garcia et al. (2021).

These quality recommendations may be higher than the quality levels of many road operators today. The improvement of quality can come in several ways:

- the AVs are the solution themselves, providing the information making it possible to increase the quality – for instance by reporting the accurate location of slipperiness or traffic jam (dissolving);
- the road operators require that their contractors increase the quality, e.g. that the maintenance contractors equip their vehicles or road works sites with C-ITS stations reporting their actions and location in real time - this means changes in contracts which in turn means increase of costs for road operators, which will likely be offset by the resulting additional benefits;
- the improvements are made in traffic management centre processes and systems resulting in increased costs (investment, maintenance, operation) for road operators, which will likely be offset by resulting benefits;
- the improvements are carried out by third parties such as weather service providers or traffic information service providers.

Note that the benefits of quality improvements sometimes occur in the future and for also other stakeholders than those carrying the costs of the improvements. The quality recommendations have been compiled in Table 4-5. The recommendations are discussed below for each of the quality criteria.

Geographical coverage should be 100% for any part of the network that is planned to provide ODD attribute value awareness to automated driving systems. Naturally, this does not require that the road operator's whole network should be covered but that when the road operator decides that a specific network or part of it will offer ODD attribute value awareness support to automated driving systems, then the coverage of that network or part will be 100%. It needs to be pointed out that this can also be temporary coverage only. For instance, the road operator can decide to provide DOVA on all of its road works zones, but the DOVA will not necessarily be provided at the road works sites when the road works are over.

Availability should naturally be higher than today's minimum for any information services of 95%. The current foreseen requirement for C-ITS service availability for automated driving uses has been 99%, which means that the service can annually be out of order for at most 88 hours (average year has 8760 hours). It should be noted that the standard short service breaks carried out during low use periods are not included in the calculation.

The **performance conditions** expected from roadside equipment today are from -50 to +60 °C, and there is likely no reason to deviate from these demands.

The **coverage of data types** strongly depends on the use case and driving scenario in question as well as whether the connected and automated vehicles participate in data provision. In the traffic jam dissolving situation, the most important data types are the traffic flow speed and occupancy data, whereas in the adverse weather case the most important data items are those describing the weather conditions such as visibility, precipitation intensity and state of matter, road surface condition, wind (gust) speed, and friction. For road works situations, the location and status of the road works, the details of the local traffic management, lane availability, possible detours, and in the most advanced cases also detailed trajectory information is provided.

Table 4-5. Quality recommendations for the Distributed ODD attribute Value Awareness framework concerning various use cases.

Quality Criteria for Distributed ODD Attribute Value Awareness Framework	Traffic jam dissolving	Adverse weather	Road works
Geographical coverage	100% on designated motorways with high traffic volumes	100% on designated highways with frequent weather issues	100% on highways at road works locations
Availability	99%	99%	99%
Performance conditions	-50…+60°C	-50…+60°C	-50…+60°C
Coverage of data types	traffic flow speed, occupancy	visibility, precipitation intensity and state of matter, road surface condition, wind (gust) speed, friction	location, status, local traffic management, lane availability, detour, trajectory
Timeliness (start)	< 2 min	<5 min	< 2 min
Refreshment rate	< 2 min	< 20 min	< 5 min
Data transfer delay	< 100 ms	< 100 ms	< 100 ms
Timeliness (update)	< 2 min	< 5 min	<2 min
Latency (content side)	<1 s (C-ITS) <10 s (NAP) <1 min (NAP event info)	<1 s (C-ITS) <10 s (NAP) <1 min (NAP event info)	<1 s (C-ITS) <10 s (NAP) <1 min (NAP event info)
Location accuracy	10 m	100 m	10 cm (trajectory) … 10 m (others)
Monitoring point density	each link between major intersections	critical microclimate spots, otherwise 50 km	start and end of road works
Measurement accuracy	depends on indicator	depends on indicator	depends on indicator
Reporting accuracy	± 5%	± 10%	± 5%
Error Rate	< 5%	< 8%	< 5%
Classification correctness (non-false positives)	96%	92%	99%
Event coverage (true positives)	94%	90%	98%
Missed events (false negatives)	4%	5%	2%
Report coverage	97%	97%	97%

The **timeliness (start)** criteria has today been about 10 minutes for many information items, and in the case of events and incidents, has relied on road users reporting such directly to the traffic management centres, police or public safety answering points. In the case of road works, road operators can reach quicker times of e.g. 2 minutes by demanding such in contracts with road works operators. In the traffic jam dissolving case, 2 minutes can only exceptionally be reached on road sections with high density (500 – 800 m) of traffic monitoring stations unless the connected vehicles themselves are providers of real-time speed information. In the case of road weather information, a timeliness of 5 minutes may be reached quite easily although it can result in higher costs (communication costs for own road weather stations, service costs for outsourced stations). Note that the timeliness requirements (both start and update) should be met in 95% of the cases.

The **refreshment rate** requirements for C-ITS services have ranged from 1 to 20 minutes. As the timeliness criteria deals with the actual critical changes in the attribute information, the refreshment rate can be quite high especially for the weather and road works cases. For the traffic jam dissolving case, the refreshment rate of 2 minutes is a realistic demand ensuring also the timeliness demand.

The **data transfer delay** should be kept as short as possible, e.g. below 100 ms.

The **timeliness (update)** requirements are similar to the timeliness (start) requirements. In the traffic jam dissolving case the possible minimal risk manoeuvres coinciding with traffic flow speed increases can mean higher crash risks. Such events are likely very rare.

The **latency (content side)** requirements foreseen for advanced use cases to be 5 minutes and in the case of C-ITS 1 minute when the data is being provided via a NAP (National Access points). Note that the requirement means that in 95% of cases, the latency is below the threshold. The C-ITS latency requirements are tighter - 1 second only when the content is provided by the C-ITS station.

The **location accuracy** of events and incidents informed and warned by the road operators has usually been on the accuracy of links between intersections. In practice this could mean an accuracy of 0.5 to 10 km. The C-ITS service quality requirements for location accuracy have been set to a range of 10 to 500 m. The 10 m location accuracy is a reasonable requirement for automated driving but only achievable via infrastructure at special hot spots only such as roadworks sites, where the exact layout accurately positioned uploaded to the cloud can be provided to the vehicles. On the other parts of the network such accuracy can be reached only by utilising the connected vehicles themselves to provide the location accuracy required for both weather, traffic and any incident related information. With regard to road works information, the road operators can ensure via contracts with the road works contractors that the road works locations are provided in 10 m accuracy and the trajectory recommendations with up to 10 cm accuracy sometimes in the future.

The **monitoring point density** of the road operators is typically for the main roads one traffic monitoring point between major intersections but can also be higher on sections with traffic flow related dynamic traffic control systems. Road weather station density can be on average one per 50 km or lower in areas with very infrequent adverse road weather problems. Specific problematic microclimate areas such as road in fog prone valleys, bridges prone to freeze, or long bridges with strong crosswinds could be also equipped with road weather stations or specific sensors. In the future, both ends of fixed road works zones or mobile roadworks or maintenance vehicles will be equipped with a C-ITS station providing real-time information of its exact location.

The **measurement accuracy** depends on the attribute in question, and a general recommendation is difficult to give. It has to be accurate enough to fulfil the reporting accuracy and error rate requirements.

The **reporting accuracy** should be within 5% of the true value for traffic flow and road work related data and within 10% for road weather related data.

The recommended **error rate** in C-ITS services has been between 5 and 10% for human drivers with 1% foreseen for automated vehicles in the future. Here we propose an error rate of less than 2% for traffic jam dissolving and road works related data as well as 5% for road weather related data based on experiences with infrastructure-based monitoring systems. There error rates relate to deviations of 10% from the true values for traffic and road works related data, and deviations of 15% for road weather data.

Concerning **classification correctness (non-false positives), event coverage (true positives),** and **missed events (false negatives),** the recommendations reflect the current warning services. The highest quality requirements systematically apply to road works data for which the road operator has the best control as they are procuring the services and can thereby set the quality level requirements to a reasonable level. The requirements are the lowest for road weather data as there the road operators' control over the whole phenomenon is weakest.

The **report coverage** requirement is 97% already for safety related traffic information at the advanced level of the road operators. This requirement can apply to all of the attributes.

These quality recommendations will be finalised in the final version of this deliverable in 2023 based on feedback from ADS developers and national road authorities.

4.4 Quality management

The road operators have compiled the quality monitoring and management methods currently used for the information services used by them or utilising their own information systems in the EU EIP Quality Package (Kulmala et al. 2019). The methods compiled are listed below with short descriptions of the methods.

1. Continuous monitoring of equipment performance and availability

The method is intended for continuous monitoring of the functioning of the existing detector network. The aim is to get timely alerts about malfunctioning equipment in order to fix or replace them. The monitoring process may be automated or performed by a human user. The monitoring of equipment performance may include verification of the availability of the data produced by the equipment, check of consistency between the data values measured by the same equipment, comparison of the measured data to other equipment adjacent to or in the same geographical area, and monitoring of error messages and alerts generated by the equipment.

2. Manual verification of events or conditions based on current reality

The manual verification focuses on correctness of reported event occurrence or reported conditions. It is mainly used for verification of manually reported events or conditions. The relevant questions are: Does an event occur (at the reported location)? Is the reported type and dimension of the event or condition correct? Is the reported location of the event or condition correct? The methods used to check information against the actual reality depend on personal and technical equipment. If CCTV cameras do exist at the respective road section, these can be used for manual verification. Otherwise, this can be done by field inspection. The road traffic police could verify reported safety-relevant events or conditions by road inspection in line with danger prevention.

3. Reference testing of data collected

Reference testing of collected data includes practices that are used to verify that traffic condition, travel time or event information produced by a certain method is correct. The data or information under analysis is compared against a source known to be reliable (ground truth). The comparison is made for a limited period of time or limited amount of data in the context of an existing traffic information service. Many times this methodology is linked to purchasing information from a private company or piloting, implementation of new data collection or processing methodology or when any other changes are introduced to the service. Reference testing of data requires a ground truth – data which can be considered to be correct with high probability. In addition to the ground truth, also other data sets may be used to support the conclusions of the analysis. The accuracy of analysis results is dependent on the quality of the data set used as ground truth.

4. Time-space oriented reference test methods

This group of methods consists of several methods, some well-established and widely used and some more experimental. With these methods, it is possible to compare the measured values in time and space – the data set under study – to the ground truth. The methods include QKZ, QSRTI, QRTTI and QFCD all described in some detail by Kulmala et al. (2019).

5. Monitoring of data completeness and latency

The objective of the automated monitoring of latency is to monitor the processing times of information in traffic information centre (TIC) or traffic management centre (TMC). It may also be implemented for other purposes. Automated monitoring of latency is typically implemented with software that automatically registers the time stamps of incoming/outgoing information related to a certain event within an organisation. This allows a statistical analysis of the performance of the operator in the processing of the event and message provision.

6. Regular sampling of message or data content completeness and correctness

Content samples of distributed traffic messages are at regular intervals (e.g. a month) manually checked for correct message and data content. Typically, a sample of around 20 % of distributed traffic messages of certain event types and around 20 % of certain operator processes are collected and checked by a person not having prepared the messages. The event types checked are e.g. objects on the road and crashes. The processes to be checked can be e.g. damage on road reports and traffic control (VMS) settings. Specified parameters for the messages and reports are checked. If the quality requirements are not met, improvements will be made for the next period. Other types of messages and processes as well as parameters could be checked in the same way.

7. Verification and calibration of traffic or weather condition prognosis

The method allows constant verification of the prognosis regarding traffic conditions/travel time or road weather. The prognosis is systematically compared to the measured condition at the time in question, and the algorithm is calibrated accordingly. The methods used for weather and traffic forecasts are partly the same. Methods for forecast verification are provided for both for forecasts involving categorical and continuous variables. In case of a forecast with a non-probabilistic categorical variable, contingency tables and related measures can be used to illustrate and evaluate the quality of the forecast.

8. Surveys of perceived quality by users

The aim of a user survey is to measure how the end users experience/perceive the traffic information services. Data collection may be performed periodically (e.g. once a year).The degree of satisfaction, the degree of relevance, the user needs and the perceived quality are covered by the survey, which can also contain other questions not linked to the quality. Specific attention should be given to the representativity of the survey respondents with regard to the target groups (drivers of specific vehicle types, users of specific service or road, age and gender, etc.).

9. Collection of direct user feedback

Collection of direct user feedback means using different channels established by the service provider to collect feedback from the users regarding the quality of the service in question. In quality assessment, collection of direct user feedback is a relatively easy way to get information about how the actual users of the service experience the service quality. The feedback can be collected via webpage, where the feedback can be classified by the user and directed to the responsible parties. The feedback can also be collected by telephone, which requires more resources for registering the feedback. User feedback is a very important method considering consumer information services (end user services) but can also be applied to B2B-type of services such as Content Access Point.

10. Monitoring of service use statistics

This method monitors the amount of service use to assess effect of service content and quality by using counters of internet page visits, smartphone application downloads and use etc. The method provides only indirect information of service quality, but it is important as the main purpose of service quality is to provide benefit to the users of the service. The users will only use a service if it provides such benefit, and thereby service use statistics are essential for the service providers.

Table 4-6 summarises the purposes for ´which the methods can be applied, the coverage of the methods in the information service value chain, their applicability to quality assurance or assessment, applicability to event or status oriented information and assessment of individual pieces or types of equipment or the service process.

The methods listed above do not cover all available methods used today for the quality management and assessment of traffic and vehicle related information. It is also likely that technically more advanced and increasingly automated quality monitoring and assessment solutions will be needed and developed for automated driving related data and information. However, today the European road operators are utilising the methods of Table 4-6 for assessing and ensuring the quality of their information services and systems.

General software and data quality standards also exist. The ISO/IEC 25012 Data Quality model represents the grounds on which the system for assessing the quality of data products is built. In a Data Quality model, the main Data Quality characteristics that must be taken into account when assessing the properties of the intended data product are established. The Quality of a Data Product may be understood as the degree to which data satisfy the requirements defined by the product-owner organization. Specifically, those requirements are the ones that are reflected in the Data Quality model through its characteristics (Accuracy, Completeness, Consistency, Credibility, Currentness, Accessibility, etc.) (ISO 2022)

Table 4-6: Summary on applicability of analysed quality assessment methods and practises. (Kulmala et al. 2019)

Nr	Method	Objective				Coverage of value chain				Assess ment / assu-rance		Event / status		Type of service / equip-ment	
		Assessment of service	Acceptance testing	Feasibility / testing new procedure of algorithm	Internal quality control / monitoring	Content detection	Content processing	Service provision	Service presentation	Quality assurance	Quality assessment	Event	Status	Equipment	Process
1	Continuous monitoring of equipment performance and availability	X	X	X	X	X				X		X	X	X	
2	Manual verification of events or conditions	X	X	X	X	X	X	X	X		X	X		X	X
3	Reference testing of data collected	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	Time-space oriented reference test methods	X			X	X		X			X	X			X
5	Monitoring of data completeness and latency	X			X	X	X	X		X	X	X	X	X	X
6	Regular sampling of mes-sage or data content comp-leteness and correctness				X		X			X		X			X
7	Verification and calibration of traffic / weather conditions prognosis	X	X	X	X		X	X	X	X	X	X	X		X
8	Surveys of perceived quality by users	X			X	X	X	X	X		X	X	X	X	X
9	Collection of direct user feedback	X				X	X	X	X	X		X	X	X	X
10	Monitoring of service use statistics	X						X	X	X	X	X	X		X

5 Harmonisation of data exchange

5.1 Introduction

Due to the diverse set of stakeholders involved for the successful implementation of the DOVA framework for safe deployment of CAD systems, harmonisation of data exchange is essential. In the context of DOVA implementation, harmonisation needs to be done at two levels:

- Data content level
- Data format level

Such a harmonisation process can be viewed from both the ADS developers' perspective as well as the road operators' perspective. Furthermore, we foresee that data exchange between these stakeholders will need to happen in two phases. An initial discussion phase will entail development of an understanding of the possibilities of implementing DOVA for a CAD system deployment in a particular area. The second, the deployment phase will entail the actual exchange of data between the CAD system and the DOVA operator fusing the off-board sensing and traffic management infrastructure as well as probe vehicle data.

5.1.1 Initial discussion phase

Before the deployment of the CAD systems and the real-time operation of DOVA, the road operators and the CAD system developers need to align their expectations with each other. Such discussions will involve understanding of the ODD of the CAD systems and the availability of the ODD attribute information via off-board sources facilitated by the road operators or other service providers. As the ODD information is always safety critical the alignment of expectations should have good possibilities of success.

For such discussions to be fruitful, it is important that the stakeholders have the same understanding of ODD attributes and use the same language. Therefore, harmonisation would be needed both for the data content and data formats.

5.1.2 Deployment phase

For any ADS design implementation, if a developer is incorporating DOVA into their system design, the developer will need to make certain assumptions about the data it can source from off-board systems (e.g., server, infrastructure, etc.). The realisation of these assumptions is likely to vary between road operators or countries because in order to make ODD attribute information available, infrastructure investment will be required. It might be prudent to suggest that a minimum level of "data" availability could be harmonised across road operators in order to aid system designs. However, we believe that harmonisation at the "data content level" will initially be done at a national level.

As information is being shared among stakeholders with different backgrounds, a common language or format is required (irrespective of the content) to convey the information. This is essential for ensuring that the information content is coherently interpreted at both creator and consumer ends. Various information exchange standards exist in this regard e.g., DATEX II series. While the DATEX II (EN TS 16157) series is widely used in the traffic management ecosystem, the information data model doesn't lend itself well for exchange of ODD attribute information. One could still use the format if the data model could potentially be adapted to reflect the full range of ODD attributes.

5.2 Methods and processes for the exchange of data

As the road operators should not force design architectures on CAD system developers. The ADS developers can design their system according to their preferences as long as it fulfils the safety and other necessary requirements seen appropriate by the authorities. In order to realise the Distributed ODD attribute Value Awareness concept, information (data) could be acquired via three means:

- Acquisition through on-board (vehicle) sensing
- Acquisition through off-board server information
- Acquisition through off-board sensing (e.g., infrastructure-based sensors)

As mentioned in Khastgir et al. (2023), ADS developers can choose to acquire their ODD attribute information in a variety of ways. The choice can be based on the availability of off-board information or sensing, the information update rate and/or criticality of the information. We foresee three potential scenarios for information acquisition between on-board and off-board sensing:

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

For our use cases (section 1.6), in the near term, while the infrastructure is not yet ready to provide ODD attribute information, we foresee scenario 1 to be prevalent. 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, we envision scenario 2 will not be applicable, even in the long term.

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%".

Such a decision-making process would benefit from a handshake agreement between the road operators and the CAD system developers. As part of this 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.

We propose the following steps for achieving the handshake agreement:

Steps	Road operator responsibility	CAD system developer responsibility
Step 1	-	ODD definition of the CAD system using industry standards (see 5.3)
Step 2: Seek agreement on ODD attributes	Sharing details about ODD attribute information to be available via infrastructure support, by location and planned deployment time	Sharing details about which ODD attributes' information are needed for DOVA by CAD system
Step 3: Seek agreement on information quality requirements	Sharing details about quality metrics for the ODD attribute information that will become available	Sharing information about minimum quality requirements for information on ODD attributes needed from infrastructure
Step 4: Agreement reached?	Supply DOVA information	Deploy CAD system

From a road operator perspective, step 2 and step 3 will imply the need for infrastructure investment. Therefore, it would be prudent to identify the set of ODD attributes (and corresponding quality requirements) which both serve the majority of the CAD system developers' needs and are realistic to achieve from an infrastructure perspective.

As mentioned in Khastgir et al. (2023) and section 3, prioritisation of the attributes could be done on a variety of dimensions. It could be done based on safety critical information or the dynamic nature of the information. For example, information about the physical infrastructure that doesn't normally change very often (usually provided by digital maps) could be provided via national access points.

Figure 5-1 provides a logic flow for such a decision-making process.

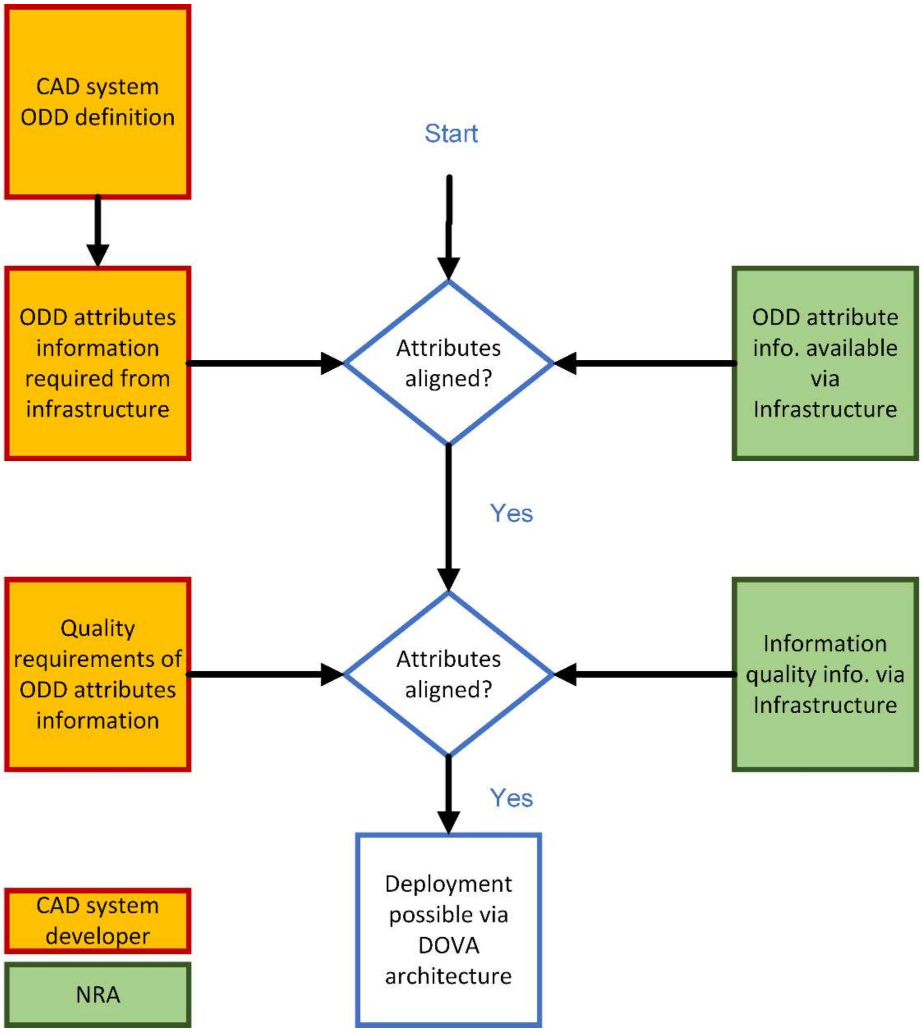

Figure 5-1: Logic flow for decision making process for implementing DOVA

5.3 Standards for data exchange

We recommend the use of standards for both phases of DOVA framework implementation (in-discussion phase and deployment phase) for both the data content and data formats. The use of these standards need to be approved by the relevant stakeholders.

For the **"in-discussion"** phase, we note:

- **Data content:** upcoming ISO standard – ISO 34503 which provides a taxonomy for ODD definition. In case extensions are made to the standard (which is reasonable due to the extensibility feature of a taxonomy), extended attributes should be clearly defined along with their relationships with the existing attributes.
- **Data format:** ISO 34503 which also provides a natural language format for ODD definition.

For the **“deployment”** phase, we recommend:

- **Data content:** same as for the “in-discussion” phase.
- **Data format:** DATEX II (EN TS 16157 series). However, the data model of the DATEX II series is not fit for purpose for an ODD definition. There is potential to adapt the data model to make it align to ODD taxonomy standards.

5.4 Recommendations for harmonisation

Our recommendations for harmonisation for implementing DOVA can be grouped into three key themes:

- **Methodology for DOVA implementation:** It is essential that various road operators follow a similar methodology for implementing DOVA. While we do appreciate that various road operators will provide different ODD attribute information via infrastructure support, the implementation could be as harmonised as possible. This would provide consistency for CAD system developers when they interact with different road operators.

- **ODD attribute data content**: Road operators should use a common ODD taxonomy to ensure all stakeholders (road authorities and operators, traffic managers, service providers, vehicle fleet operators and managers, CAD system developers) have a common understanding of ODD attributes.

- **ODD data format**: To realise DOVA, road operators need to agree on a data format for exchanging ODD attribute information.

6 Governance of data and data exchange

Discussing the DOVA framework is tied to various aspects such as who delivers which information, to whom, how are quality and security taken into account, what data formats should be used, etc. In this chapter we provide more insights into these, as well as discussing how interactions between stakeholders can occur.

6.1 Contextual background

The role of C-ITS information in the vehicle driving process differs on the basis of who is the actual driver and user of the information. To put it more concretely, the automation level of the vehicle in question is very determining in this respect.

- For example, in a typical current-day C-ITS situation a driver receives information via perhaps an app or perhaps information sent from a service provider directly to the vehicle which has an on-board subscription to such a service. It is then up to the driver to decide what to do with it. It is in essence the driver that chooses and decides whether or not to act on the information that is provided to him/her.
- In a more future case, this logic changes for a vehicle with a sufficiently high level of automation (i.e., SAE L4). There we would assume that the automated vehicle, through its algorithms, takes an action based on or reacts to the information provided.

Given this background, we determine that – for the correct rollout and adoption of the DOVA framework – it is needed for:

- ADS developers and AV fleet operators to agree on using the previously described information and data, stemming from external sources in general and from road operators in particular,
- and for road operators to commit to deliver said information and data, either stemming from their own sources or third parties.

Note that, on the operational level, there is a fine line of liability here, in that the information provided to (L4-)vehicles would typically be information that either augments their sensors (“see more”) and accompanying horizons (“see further”), or takes the form of (traffic management based) advice given to them. In both cases it nevertheless is the vehicle that ultimately remains responsible for any action undertaken. In this way, the C-ITS information trickles down to the vehicle, at which point the latter uses it in its internal algorithms for (adjustments of) vehicle control.

6.2 Requirements for information and data

From the AV owner, OEM or fleet operator perspective, there might be some hesitation to ‘just’ share (all) their information and data. One way to deal with this, is to rely on the Safety-Related Traffic Information (SRTI) delegated regulation for the ITS Directive. As long as information and data are considered to be safety-critical according to the delegated regulation, there is the obligation to share it. The rest can then be considered on either a case-by-case or a group-level basis. A guiding principle therein would be what the added value of the information and data is, and to whom this added value manifests itself. Examples are data that provide some level of redundancy (complementing data), or that provide a way for assessing / double checking its verity (competing data). They can then be classified as Must haves, Should haves, Could haves, and Won't haves (e.g., the MoSCoW approach).

It is also possible that a purely private sector solution will emerge to share vehicle sensor based data with all vehicle fleets, but this is regarded as quite unlikely based on earlier experiences.

From the road operators' perspective, it is necessary that they deliver the right information and data at the right time to the right vehicle. To accomplish this, several requirements must be taken into account (non-exhaustive list):

- Content
- Quality
- Timeliness
- Cyber security
- Format

Here a central tenet is that these requirements have to be agreed upon upfront between road operators and OEMs. They would then typically be formulated as KPIs. But how is this done? A possible way that governs this process is to set up a central body in which all stakeholders are represented, in which these requirements are discussed, drafted, and finalised. This would then also imply the adoption of the chosen standards and other relevant aspects. As such, it becomes an ongoing dynamic process to decide what ODD attributes are relevant, starting with a selection, and then evolving into collecting and sharing more attributes. Another issue is related to quality and cyber security requirements. These may evolve over time, and hence have their place in the discussions within such a body.

For aspects such as quality, timeliness, and the format of information and data, we refer to the discussions in earlier Chapters 3, 4, and 5. A crucial input here is the one provided by the Hi-Drive consortium (in which a significant amount of OEMs are present, and which forms a sort of continuation of the L3-Pilot project, at least for when it comes down to the adopted standards for data formats). The Hi-Drive use case descriptions (Bolovinou et al. 2023) so far do not contradict our findings.

A final word regarding open data. In principle it does not matter whether data is truly open or not, at least not for the purposes of quality and security assessments. All data, regardless their dissemination and access levels, must comply with the afore-mentioned standards and agreements.

6.3 Exchanging information and data

Note that especially for exchanging the data, we see several important points of attention. What platform / process is to be considered in order to facilitate and publish this in an agreed upon manner? If digital twins will form a key component in this process, then an additional question also is how the information and data flows to and from them. For this latter aspect, we rely on the results of the DiREC project.

Data sharing and governance trials have been introduced in Europe as also promoted by the European data strategy (European Commission 2022). For example, GAIA-X and KRAKEN projects, and from the CAD field the L3Pilot initiatives have introduced data exchange between project partners (ARCADE 2021). In addition, there are two good examples of partnerships with wider and long-lasting effort to build common data exchange governance: Data for Road Safety and National Access Point Coordination Organisation for Europe (NAPCORE) which are described below.

Example of more mature data exchange framework governance in the field of connected and automated driving is the Safety Related Traffic Information (SRTI) Ecosystem. The SRTI ecosystem, originally named as Data Task Force, was set up by Member States, the European Commission, and the automotive and telecom industry after the Declaration of Amsterdam (Rijksoverheid 2016) and High Level Meeting in 2017. The SRTI ecosystem was eventually set to speed up the implementation of European Commission delegated regulation, supplementing the Intelligent Transport System directive 2010/40/EU, on data provision of road safety-related traffic information free of charge to users (EUR-Lex 2013). The ecosystem improves road safety by maximizing the reach of safety-related traffic information with data sharing between vehicles and infrastructure. After setting common principles for data exchange and signing Multi-Party Agreement (Data for Road Safety 2020), a General Assembly was established by the public and private members to safeguard and continue to evolve the ecosystem. Several tech working groups have been established to continue development and ease onboarding of SRTI data and new partners. (Data for Road Safety 2022)

Similarly, as Data for Road Safety SRTI ecosystem, the EU Member States have launched National Access Point Coordination Organisation for Europe (NAPCORE) to coordinate and harmonise Member State NAP mobility data platforms in Europe. Common European coordination mechanism aims to improve interoperability of the NAPs data exchange. The EU funded project with 36 partners lasts until the end of 2024 but aims for long-lasting platform organisation. (NAPCORE 2022)

Given the high safety-criticality of most of the ODD-related local condition information attributes, a similar setup like the Data for Road Safety SRTI ecosystem would logically be a workable solution for the DOVA exchange of data as well.

6.4 Managing the DOVA framework

Given the different stakeholders involved, and the different types of information and data flowing, a central question then becomes: who is in control of the DOVA framework? Where does the management of this lie? Here, several different types of models can be considered. Will there be a single, central point of collection, or will it be set up in a distributed fashion? A possible implementation of a central role would be 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 a public-private partnership, in which the government also commits itself to providing information and data according to pre-agreed upon specifications.

In the Vreeswijk et al. (2023) we elaborate further on these ideas, giving thought to relevant organisational structures, types of data being exchanged and how this is done. Another important aspect before being able to set up a governance structure is that all involved stakeholders fully understand the DOVA framework. Therefore, it would be good have the framework and it’s road operator perspective published or recorded in addition to the TM4CAD deliverables (e.g. by ERTRAC or in a Hi-Drive guideline).

Finally, for a functioning DOVA framework several measures are taken into account in order to comply to the General Data Protection Regulation GDPR. The data to be collected is restricted to the essential data only and storing the data should also be restricted. If personal data is necessary for the DOVA in some case pseudonymisation techniques should be applied. Note that data from a road authority doesn’t need to be anonymous as on the contrary you want this to be known so you can attribute a trustworthiness level to it. A GDPR officer should be assigned to oversee the DOVA framework and its operation.

7 Discussion

7.1 Answers to the Research Questions (RQs)

This chapter presents conclusions for the four Research Questions (RQ4-RQ7) of the CEDR call 2020 TM4CAD project's Work Package 3 „Information exchange between traffic management centres and automated vehicles – information needs, quality and governance".

RQ4: What kind of information is to be transmitted in the interaction (in both directions) between TMC and vehicle?

The TM4CAD analysis of the four ODD/local condition clusters (Khastgir et al. 2022) information priority levels concluded in a list of local condition attributes. This deliverable assessed the importance, safety criticality and additional/reduced costs involved for the attribute information, and finally prioritised the attributes. The overall priority was based on

- three actors of maintenance operator, traffic manager and automated vehicle or Automated Driving System developer,
- actor's need for the information and information safety criticality,
- three scenarios of traffic jam, adverse weather area and static/dynamic road work zone.

The TM4CAD analysis results were validated by survey and workshop with the vehicle manufacturers (ADS developers) as well as reviewed by the National Road Authorities. One ODD (local condition) attribute's priority level was lowered from HIGH to MEDIUM due to ADS developers' feedback: remote human support. Some of the ADS developers indicated this being more long-term service and now prioritized lower although remote support will likely re required to deal with edge cases. Attributes with mild disagreement, i.e., GNSS coverage NOT available, wind speed, special lightning conditions, wet pavement, and road surface friction, were kept equal with the results as half of the respondents agreed with the TM4CAD analysis.

Table 7-1 lists the high priority local condition attributes. The tables containing all attributes are provided in Chapter 3.

Table 7-1: High priorities among local condition / ODD attribute information.

Physical *attributes of the roadway and its environs*
Locations of road boundaries
Geofence/geographic area
Zone boundaries
Roadside landmarks
Quality of pavement marking visibility
Road geometry constraints
Road shoulder conditions on both sides
Notifications of locations with occluded visibility
Digital infrastructure support
Variable message sign contents
Locations where V2I/I2V communications are available
Locations of incidents that represent traffic impediments or safety hazards
Current average traffic speed and density by lane and road section
Special events creating abnormal traffic conditions and their locations
Temporarily blocked or closed road locations
Highway shoulder locations occupied by vehicles or debris
Locations with dynamic traffic access changes
Dynamically varying ambient environmental conditions
Visibility range with rain/snow/sleet/hail in visible light spectrum
Visibility range with rain/snow/sleet/hail in lidar infrared spectrum
Rainfall rate in mm/hr
Snowfall rate in qualitative ranges
Visibility range with other particulate obscurants in visible light spectrum
Visibility range with other particulate obscurants in lidar infrared spectrum
Predicted significant changes in key weather attributes
Electromagnetic interference
Wet pavement surface
Ice on pavement surface
Cold pavement surface (potential for ice if wet)
Road surface friction

Table 7-1: High priorities among local condition / ODD attribute information. Continued from previous page.

Dynamically varying ambient environmental conditions (continued)
Light to moderate snow/slush accumulation on surface
Heavy snow/slush accumulation on surface
Light to moderate flooding (puddles) on surface
Heavy flooding – potentially impassable to low-profile vehicles
Operational attributes of the roadway
Temporary static signs
Maintenance vehicles using portions of carriageway
Work zones
Incident recovery events (crash scenes, crime scenes, dropped loads, landslides, avalanches…)
Availability of specific C-ITS information services
Availability of real-time merging guidance or assistance at motorway interchanges or entrance ramps
Real-time lane-specific speed limit information availability at specific locations.
Obstacles or debris on road surface
Traffic rules and regulations in digital form, updated in real time

RQ5: Which information is to be provided by the NRA/roadside and which information can be obtained by the sensors of the moving vehicle itself?

According to the AV industry feedback in the survey and workshop, the vehicle manufacturers and ADS developers mainly rely on the information that the vehicle sensors provide. This is done especially for road safety and liability reasons. Any external ODD or local condition information from infrastructure can bring redundancy, i.e., backup for the automated driving systems, but the trustworthiness of the information is a concern because the manufacturer bears the responsibility for the outcome of using the information when the vehicle is used in the automated mode. In any case, the ODD-related external information can likely always be regarded at least as “nice-to-have” as it can extend the electronic horizon of the vehicle beyond the range of the vehicle sensors.

If in the future driving rules for ADS would specify that ADS adhere to authority directions and information in specific conditions, national legislation may require the road authorities and/or operators or other infrastructure-based sources such as information service providers to provide the related information attributes to the ADS. Some of these information attributes are necessary for ADS operation while others are relevant to managing the traffic.

Basically, the ODD / local conditions attributes that the AV industry indicated being priority for them, were also considered priority for the traffic managers and road maintenance operators in most of the cases in the three scenarios of traffic jam dissolving, adverse weather area and static/dynamic road work zone. Thereby the road operators and actors working for the road network operation need the local condition information attributes and will set up their own monitoring systems or acquire that information from various data providers. The deliverable also highlights that the automated vehicles themselves are also important data providers also to the road operators. The latter applies especially to cases where good and comprehensive road network coverage, location accuracy, and timeliness is required.

RQ6: When and how should such information be available?

This deliverable presents a number of recommendations for the future availability of the DOVA and its local condition / ODD information attributes. The overall DOVA information exchange needs to be available for L3/L4 vehicles for 99% of the time in the future with considerable traffic flow penetration of such vehicles. All time related quality recommendations have been compiled in Table 7-2.

Table 7-2. Time-related quality recommendations for the Distributed ODD attribute Value Awareness framework in the future concerning various use cases on highways and motorways.

Quality Criteria for Distributed ODD attribute Value Awareness Framework	Traffic jam dissolving	Adverse weather	Road works
Availability	99%	99%	99%
Timeliness (start)	< 2 min	<5 min	< 2 min
Refreshment rate	< 2 min	< 20 min	< 20 min
Data transfer delay	< 100 ms	< 100 ms	< 100 ms
Timeliness (update)	< 2 min	< 5 min	<2 min
Latency (content side)	<1 s (C-ITS) <10 s (NAP) <1 min (NAP event info)	<1 s (C-ITS) <10 s (NAP) <1 min (NAP event info)	<1 s (C-ITS) <10 s (NAP) <1 min (NAP event info)

The processes and technologies for the exchange of the data between roadside systems and the automated vehicles have been described in chapter 5 of this deliverable. The governance framework for making this information available is discussed in chapter 6. The governance solution demands a consensus among the main stakeholders including vehicle manufacturers, ADS technology developers, fleet operators, information service providers, digital twin providers, national, regional and local governments, road authorities and operators, and traffic managers. As most of the attribute information was found to be safety-critical, a set-up likening the Data for Road Safety SRTI ecosystem could be a workable solution.

RQ7: How to define and measure the quality/correctness of such information?

Chapter 4 of this deliverable provides a recommendation for the quality indicators and their values. Table 7-2 is an example of the latter.

In addition, the feasible quality assessment and assurance methods have been proposed in the same chapter.

7.2 Open issues

A primary open issue is the basic one of trust. Vehicle manufacturers and ADS developers will use the data as a basis for automated vehicle operation only if they can trust the data to be correct, reliable and secure. Much work needs to be done to improve the quality of the data, the reliability of the data and its exchange as well as the cybersecurity of the DOVA-process to the level satisfying the liability-related requirements of the automated vehicle industry.

A generic issue is how to maintain and share the digital infrastructure of the road operator. The uses of the road operators' digital infrastructure including also the DOVA framework are numerous as are the sources and suppliers of the contents of the digital infrastructure.

Another key open issue is the governance of the DOVA and the data exchanged via it. An agreed governance model is a prerequisite for operating such a framework in practice. Access to in-vehicle information was debated in Europe for decades before the data for road safety SRTI ecosystem was finally set up while covering only a small part of the information attributes.

Many details of the DOVA are yet to be solved including:

- which information attributes are selected to be included in DOVA taking into account all possible scenarios in addition to the three now addressed
- what quality requirements apply to specific information attributes as the requirements may vary greatly between different attributes
- detailed cybersecurity solution
- protection of privacy
- protection of intellectual property rights
- technology solutions for data exchange
- harmonisation and standardisation of the DOVA framework
- how to ensure the awareness of traffic managers of the use of the automated mode and especially the occurrence of minimal risk manoeuvres by highly automated vehicles
- needs to harmonise the involvement of road operators and traffic managers in DOVA implementation
- harmonisation/standardisation of the ODD attribute data content and data format

8 Conclusions

8.1 Progress to the Research Questions and Expected Results

The following table summarises achievements, knowledge gaps and future research activities related to the Research Questions (RQ), Essential Results (ER) and Operational Results (OR) that are addressed by the TM4CAD project in this deliverable.

Table 8-1: *Answers to various research questions and essential results addressed by D3.1*

Research Question / Essential Result	**Achievements and gaps**
RQ4: What kind of information is to be transmitted in the interaction (in both directions) between a traffic management centre and vehicle?	This deliverable assessed the importance, safety criticality and additional/reduced costs involved for the attribute information, and finally prioritised the attributes. The overall priority was based on the viewpoints of three actors of maintenance operator, traffic manager and Automated Driving System developer in connection with three scenarios of traffic jam, adverse weather area and static/dynamic road work zone. The TM4CAD analysis results were validated in liaison with ADS developers and the National Road Authorities.
RQ5: Which information is to be provided by the NRA/roadside and which information can be obtained by the sensors of the moving vehicle itself?	We found out that any external ODD or local condition information from infrastructure can bring redundancy, i.e., backup for the automated driving systems. The ODD attributed related external information can likely always be regarded at least as "nice-to-have" as it can extend the electronic horizon of the vehicle beyond the range of the vehicle sensors. In the future, regulations could specify that the road operator or traffic manager must provide specific information attributes to the ADS. Some of these information attributes are necessary for ADS operation while others are relevant to managing the traffic. Basically, the ODD / local conditions attributes that the AV industry indicated being priority for them, were also considered priority for the traffic managers and road maintenance operators in most of the cases in the scenarios of traffic jam, adverse weather area and road works. A primary open issue is the basic one of trust. Vehicle manufacturers and ADS developers will use the data as a basis for automated vehicle operation only if they can trust the data to be correct, reliable, and secure. Much work needs to be done to improve the quality of the data, the reliability of the data and its exchange as well as the cybersecurity of the DOVA-process to the level satisfying the liability-related requirements of the automated vehicle industry.

Research Question / Essential Result	Achievements and gaps
RQ6: When and how should such information be available?	This deliverable presents a number of recommendations for the future availability of the DOVA and its local condition / ODD information attribute values. The overall DOVA information exchange needs to be available for L3/L4 vehicles for 99% of the time in the future with considerable traffic flow penetration of such vehicles. All relevant time related quality recommendations are presented in chapter 4. Chapter 5 discusses the means of data exchange and proposes the use of standard data exchange solutions already in routine use by the road authorities and operators such as DATEX 2. The obvious gap is the lack of harmonisation/standardisation of the ODD attribute value data content and data format. The practicality of the presented recommendations needs to be validated.
RQ7: How to define and measure the quality/ correctness of such information?	Section 4.1 details the quality indicators to define the quality of the information and sections 4.2 and 4.3 the recommendations for the quality requirements with regard to the different indicators. Section 4.4 lists the quality management and measurement methods recommended for measuring the quality in practice. The gap is the lack of certification and validation of the quality indicators and requirements for actual ADS in development or available on open roads.
ER3: Determination of the information needs and who is to provide this information in the bidirectional interaction between TMC and vehicle.	Chapter 2 identified the information needs of the ADS in addition to those of the traffic managers as well as road works and winter maintenance operators on the ODD / local condition attribute level in the three scenarios of traffic jam, adverse weather and road works. Chapter 3 continued by prioritising the information needs for each of the above-mentioned stakeholders and also provided a synthesis of these. One of the main results was that any external ODD or local condition information can bring redundancy for the AV, i.e., backup for the automated driving systems, but the information is only used if the ADS can trust the source In TM4CAD the information needs were not validated with a large sample of stakeholders from all European countries, and this should be accomplished. The same applies to the roles of the different stakeholders in the DOVA information provision.
ER4: Description of the properties of this information (availability, reliability, accuracy, detail, latency, standards, …) and the required/desired reaction of the vehicles;	The properties are described in detail in chapter 4 for the DOVA framework as well as event and status type of information attributes. In addition to the validation gap mentioned above, the quality requirements should be carefully considered separately for the different information attributes taking into account the stakeholder needs as well as technological and financial restrictions related to acquiring the information.

Research Question / Essential Result	Achievements and gaps
OR2: Description of possible governance mechanisms for ODD management that need to be established	Chapter 6 discussed the possible governance mechanisms for the data and the deployment, maintenance and operation of the overall DOVA framework. A generic issue is how to maintain and share the digital infrastructure of the road operator. The uses of the road operators' digital infrastructure also including the DOVA framework are numerous as are the sources and suppliers of the items of the digital infrastructure.

8.2 Implications for further work

The further work in TM4CAD validated the results presented in this deliverable. In WP4, this took place for a specific use case and scenario, the road works zone. In WP5, the focus was on detailing the requirements of the road authorities, operators and traffic managers towards automated vehicles and their manufacturers and fleet operators.

With regard to CEDR and its member NRAs, the work on open issues should commence in many cases in close liaison and cooperation with the automated vehicle industry stakeholders on the European level, e.g., in the scope of the Horizon Europe or CEF 2 programmes as well as on the policy level. These could lead to infrastructure-enabled solutions improving the continuity of or extending the Operational Design Domains (ODDs) with mechanisms such as extended perception and decision-making delegation, supporting the real time knowledge about conditions in the "electronic horizon", the centimetric accuracy of the positioning signal, and the ability of CCAM enabled vehicles (incl. collective awareness) to navigate through road works and incident sites. In some cases, this can also be done via the CEDR research programme and national research actions.

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