Traffic Management for Connected and Automated Driving (TM4CAD)

# Road operator and traffic centre requirements for automated vehicles

Deliverable D5.1 Version 0.7 (second iteration)

7 November 2022

This project is funded by CEDR Call 2020 Impact of CAD on Safe Smart Roads.

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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## (second draft)

Due date of deliverable: 12 August 2022

Actual submission date: 19 September 2022

Start date of project: 13 September 2021 End date of project: 12 March 2023

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# Executive summary


The project TM4CAD (Traffic Management for Connected Automated Driving) was selected in CEDR Transnational Road Research Programme Call 2020 for funding with regard to call topic C Traffic management. The project commenced its activities on 13 September 2020 and is planned to be completed in 18 months after its start.

This deliverable (D5.1) is to provide a complete set of realistically implementable requirements from traffic management systems and road operators to CAD systems and automated vehicle manufacturers. This is done by means of on-going collection of requirements, first from a technical point of view (for traffic management and CAD systems), and then highlighting the roles both the road operators and traffic management centres) and vehicle manufacturers (and Tier-1 providers, ADS developers, AV fleet managers/operators) play in this respect. At the moment, most of the requirements were given at a higher level, based on the work done in WP2 and WP3, with extra inputs stemming from the MANTRA, EU EIP, and TransAID projects. Additionally, we also looked at relevant input from the PEB and various past TM4CAD workshops. In the final version of this deliverable we will also incorporate more concrete insights and recommendations based on the interactions with the HiDrive project.

To conclude, we focused on how to best convey the recommendations to the relevant stakeholders. One method – currently adopted through workshops – is through holding an open stakeholder dialogue. The next two related steps are then to publish requirements in specific (standardisation) bodies on the one hand, and to establish a so-called codified highway code which has the ability to integrate all requirements on the long term. For the latter this deliverable provides a tangible explanation of the process.

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# 1 Acronyms and abbreviations

| | |
|---|---|
| ADS | Automated driving system |
| AV | Automated vehicle |
| CAD | Connected and automated driving |
| CCAM | Cooperative, connected, and automated driving |
| CEDR | Conference of European Directors of Roads |
| CEF | Connecting Europe Facility |
| DOA | Distributed ODD awareness |
| EC | European Commission |
| ECU | Engine control unit |
| ER | Essential result |
| EU EIP | European ITS Platform |
| HD | High definition |
| ISAD | Infrastructure Support for Automated Driving |
| ISO | International Standards Organisation |
| ITS | Intelligent transport system |
| MAPEM | MAP (topology) extended message |
| MRM | Minimum-risk manoeuvre |
| NRA | National road authority |
| ODD | Operational design domain |
| OEM | Original equipment manufacturer |
| OR | Operational result |
| PEB | Programme Executive Board |
| RQ | Research question |
| SPATEM | Signal phase and timing extended message |
| SRTI | Safety-related traffic information (Directive) |
| TM4CAD | Traffic Management for Connected and Automated Driving |
| TMC | Traffic management centre |
| TMS | Traffic management system |
| UNECE | United Nations Economic Commission for Europe |
| WP | Work package |

# 2 Introduction

## 2.1 TM4CAD

In the "*Traffic Management for Connected and Automated Driving*" (TM4CAD) project we explore the role of infrastructure systems across various Infrastructure Support for Automated Driving (ISAD) levels in creating ODD awareness for CAD systems [TM4CAD21]. As a starting point we will propose various system architectures for distributed ODD attribute information and define acquisition principles of the information based on exchange between the stakeholders, ultimately to enable CAD systems to be aware of their ODD in real-time. Moreover, TM4CAD will demonstrate 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 will provide NRAs and other road operators 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 will:

- Identify the full range of ODD attributes for consideration, based on experience from working on ODD issues in standardisation activities and in other related research projects.
- Integrate 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 awareness and the role of infrastructure in it;
- Develop recommendations based on the technical constraints of the ODD-relevant information that can be perceived and exchanged in real time by the road operators and the sensing systems of the CAD-equipped vehicles.
- Provide insights on how to support CAD operation and ODD management, and how ISAD should be refined for traffic management use.
- Detail 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 Hironao Kawashima (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 (WMG, UoW), and Anton Wijbenga (MAPtm).*

## 2.2 Objectives and target audience

The main objective of this deliverable is to provide a complete set of realistically implementable requirements, from traffic management systems and road operators, to CAD systems and automated vehicle manufacturers. In addition, it will present an evaluation of the most effective ways to document and publish them. As a solution, TM4CAD will focus on codifying the requirements digitally (pertaining to desired behaviour) into a so-called codified highway code. To enable the road operators to define *good behaviour* for CAD systems, the next step is the introduction of a novel ODD and ISAD based highway code concept, along with a common set of ODD attributes (in similar spirit as to how a *regular* highway code defines the expected behaviour from human drivers). This will enable manufacturers and road operators to communicate in a common language and allow for changes in CAD traffic throughput due to ODD and ISAD changes. This method is already being pushed forward within the UK, based on road authorities' and manufacturers' needs and interests. Simultaneously, this code will encompass expected behaviour in certain operating environments, therefore providing a close link with the ODDs and ISAD levels.

The target audience is the CEDR Programme Executive Board (PEB) coordinating the CEDR 2020 research call and the larger body of NRAs that they represent. In addition, this deliverable also addresses the OEMs to some extent.

Note that this deliverable will go through three subsequent iterations: a first draft, a second draft, and a final version at the end of the project. At this moment, the contents of this deliverable reflect the progress made for the second draft.

## 2.3 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 (D5.1):

***Table 1:*** *Mapping of Research Questions and Expected Results to Deliverable 5.1*

| Research question / result | Addressed in paragraph(s) |
|---|---|
| **RQ1**: Should NRAs set requirements on the desired behaviour of (partly) automated vehicles on where and how they should drive? | Sections 3.3.1 and 3.3.2 |
| **ER3**: Determination of the information needs and who is to provide this information in the bidirectional interaction between TMC and vehicle | Sections 3.1 and 3.2 |
| **OR3**: A vision on what requirements an NRA should set on the desired behaviour of (partly) automated vehicles, where and how they should drive | To be determined during 3rd iteration |

| | |
|---|---|
| **OR4**: As OEMs are publishing their requirements towards road design, establish what are the requirements from NRAs towards vehicles (e.g. on concepts like minimal risk manoeuvre / hand over request) from a safety perspective? | To be determined during 3rd iteration |

## 2.4 Relationship with other work packages

WP5 will not add new research and development activities to those undertaken by WP2, WP3, and WP4 (see also **Figure 1**). Instead, it will exploit the results of these work packages as well as the workshops they organise. The task of WP5 is to derive, collect, and consolidate requirements to CAD systems and the automated vehicle industry, while assessing effective ways to document and publish these requirements (e.g., through UNECE or a highway code). In this manner, WP5 adds to the work of the other WPs.

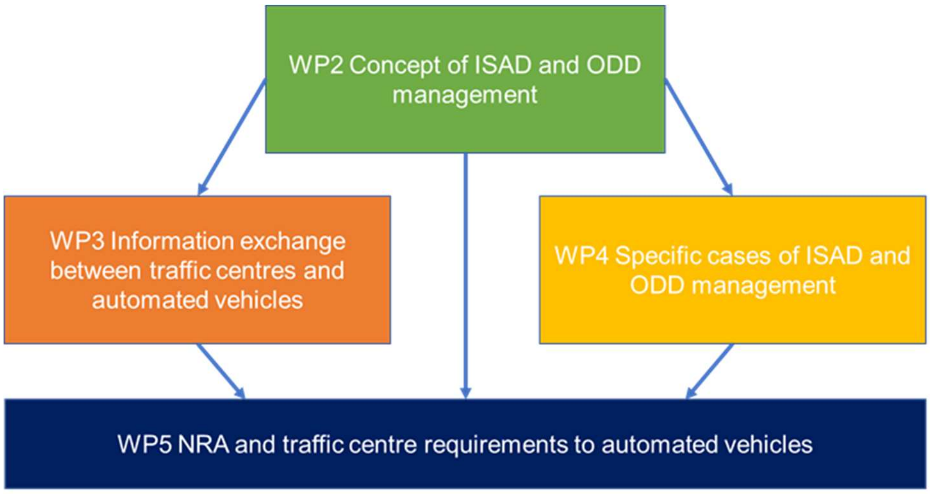


***Figure 1**: Relationship of WP5 (and D5.1) with other work pacakges of TM4CAD.*

## 2.5 Structure of the document

This report starts with an on-going collection of requirements in Section 3, first from a technical point of view (relating to existing requirements and those identified within TM4CAD), and then highlighting the roles both the national road authorities (and traffic management centres) and vehicle manufacturers (and Tier-1 providers) play in this respect. Then, Section 4 (and in particular Section 4.2) presents our proposal for a codified highway code to best convey these requirements. Finally, Section 5 summarises our conclusions at providing an answer to research question 4, i.e. whether or not road operators should set requirements on the desired behaviour of (partly) automated vehicles on where and how they should drive.

# 3 Requirements identification

In this section we collect the various requirements that are relevant for road operators in light of desired competencies and behaviour of automated vehicles. These requirements entail two views: on the one hand there is, e.g., the information that needs to be provided by automated driving systems (ADS), whereas on the other hand the point of view lies more on the information that ADS need to be able to receive and act on.

In the next sections we first focus on existing requirements from previous project such as MANTRA and EU EIP. Thereafter we list new requirements, based on TM4CAD findings. Note that these requirements implicitly take the desired behaviour of (partly) automated vehicles (including where and how they should drive) into account, while also considering the safety perspective (cf. minimal risk manoeuvres, system disengagements, and handover requests).

Finally, we highlight the roles that both national road authorities and vehicle manufacturers (and Tier-1 providers) play in this respect.

Note that for requirements related to the quality of data provisioning, we refer to Section 4 in TM4CAD's Deliverable D3.1 [TM4CAD22b].

## *3.1 Existing requirements*

The MANTRA project of CEDR and CEF-supported EU EIP project identified a number of previously suggested requirements towards OEMs and CADs [MANTRA20 and EU EIP20]. They are as follows.

- In order to reduce the increased road pavement rutting and wear, the OEMs and ADS providers should ensure **wheel path alteration** in cross-section especially by heavy vehicles closely following each other.

- Concerning HD maps and keeping them updated at all times the fleet managers and OEMs should **provide feedback on HD maps** and report any anomalies in their content.

- The AVs should provide information on incidents, e.g., by detecting stopped vehicles and roadway defects, and provide relevant incident and event related data to traffic managers as well as service providers.

- The AVs could also be used to **monitor the performance of road works management**, i.e. the impact on the traffic stream, local traffic safety, communication of the local conditions, etc.

- New approaches need to developed to **road condition data collection** for deterioration monitoring in cooperation with OEMs and CADs.

- The automated vehicles should give **external indication** of being driven by ADS or being last in platoon, to ensure safe and efficient traffic management; this way, other human drivers can take the (seemingly) different behaviour of the ADS into account.

- OEMs, fleet managers and CADs need to **acknowledge the conductor role** of road authority/ operator in traffic management (as in incident management) and see to it that the AVs act accordingly.

- The OEMs and CADs need to consider **harmonising the pictograms and message content** used by road operators and OEMs . In the future, the road users (drivers, automated vehicles, and vulnerable road users) will receive information in addition to roadside variable and dynamic message signs also via their onboard devices. For the safety of the road users, it would be good to harmonise at least the pictograms used by the different stakeholders, but preferably the whole message content.

- There is a need to develop and use **standardised communication protocols** with TMC, fleet managers, service providers, and automated vehicles.

- The safe behaviour of highly automated vehicles at the end of their ODD needs a standardised solution for the minimum risk manoeuvre, likely specific ones for different road and traffic environments. Road operators should be a key stakeholder in such standardisation actions. In the case of ODD end, the number of vehicles making a minimum risk manoeuvre can be quite large and stopping on a high-speed road such as a motorway is not a safe manoeuvre. Thereby, slowing down and proceeding at a low speed to a large parking area beside the next exit could be **a workable MRM solution** to be adopted by OEMs and CAD developers.

- The AVs must supply **information on ODD termination risks and of any MRMs** carried out with sufficient detail and location accuracy. This is essential for the safe and efficient traffic management of the road network.

- The OEMs and fleet managers need to set up and operate **fleet supervision centres** for their automated vehicles. Some national road authorities and many road operators deal with the operational maintenance and winter maintenance of their road networks. Thereby, those road authorities and operations need to set up their fleet supervision centres for automated maintenance vehicles.

- Standardisation actions need to be pursued concerning the marking and management of incident and road works sites taking into account the capabilities of and requirements towards highly automated vehicles. The **compliance to such standards** should preferably be mandated, at least on the European level. The leading or coordinating role of road authorities and operators in road incident management needs to be specifically mandated, preferably on the European level.

## *3.2 New requirements derived from TM4CAD findings*

In this first iteration, the requirements highlighted in TM4CAD mainly relate to the information that needs to be provided by automated driving systems (ADS), i.e.:

- ADS must have a clearly defined ODD, using a common set of ODD attributes.
- ADS must actively monitor the status of ODD attributes critical to safe operation.
- ADS must cease automated driving if ODD attribute information is unavailable.
- ADS must be able to act on prescriptive traffic management measures set by road operators.
- ADS must behave in line with predefined rules of the road.
- ADS should be able to act on advisory traffic management measures set by road operators.
- ADS must cease automated driving if it cannot comply to the rules of the road.
- ADS must announce to traffic centres when and where they initiate a MRM.

- ADS should let the road operators and traffic management centres know the reason behind a MRM especially if the reason is due to a factor affected by the actions of the road operator and traffic management centre
- ADS should let road operators and traffic management centres know whether the vehicle is being operated by the ADS, as this might prove useful in case a TMS requires a different approach for dealing with (highly-)automated vehicles

From our workshops we also noted the following observations which are also relevant in light of the different roles and responsibilities that we discuss further on:

- There are still some unclarities with respect to e.g., the expectations from digital twins, who hosts/manages them, high-definition maps, and all related message protocols (MAPEM/SPATEM).
    - The Car2Car consortium, as well as the AdaptiVE project contain protocols (incl. the 5GAA)
    - Information messages sent, specifically CAMs: they are time and safety critical, requiring low latencies
    - GDPR may become an issue when sending data from ADSs/OEMs to NRAs (this could also be done via an intermediary service or back-end)
- Furthermore, OEMs would like NRAs and road operators to send raw information to the ADSs, i.e. without preprocessing into a stastistic or any prefiltering of the data.
    - Example reasons are how would you define traffic dissolution (i.e. when, how, and where is a traffic jam dissolving?), what is adverse weather (this is typically a combination of ice pockets, level of precipitation, friction indices, even oil spills), etc.?
- For automated vehicles, ODDs should be as defragmented (i.e. uninterrupted) as possible to ensure smooth operations.
    - This requires answering the questions: how is the ODD defined, and can you detect/confirm it?
    - In principle, vehicles have multiple sensors to deal with this
    - Landmarks and GNSS positioning require highly accurate digital maps
- For the interaction with the infrastructure, the OEMs would like road operators to adopt and uphold the same standards as they are applied to them.
- As data sharing from OEMs to the infrastructure is a business case that involves, amongst others, road-quality data, there is a requirement to exclude liability, coverage, and funding of the data and sharing process
- Inter-brand connectivity should be pursued (in this respect, truck platooning is a good example)
- Traffic flow characteristics as attributes are not really picked up now, only for (optimal) speed advice, GLOSA(-like)
- Regarding the duration of ToCs:
    - The ToC duration of 3 to 30 seconds is more or less deemed theoretical by the OEMs
    - OEMs are actively monitoring the driver in the vehicle in order to prevent long delays (i.e. getting them below 3 seconds)
    - There are multiple conditions continuously monitored, when 2 or 3 out 5 fail the system will react)

## *3.3 Roles and responsibilities*

As the work in WP2, WP3, and WP4 progresses, we are also able to more clearly define the different roles that road operators (collectively taken to be national and regional road authorities, motorway operators, and traffic management centres) and OEMs (collectively taken to be vehicle manufacturers,Tier-1 suppliers, ADS developers and AV fleet managers/operators) have, as well as the responsibilities they have in general on the one hand, and to each other on the other hand.

### 3.3.1 Road operators and traffic management centres

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

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

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

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

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

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

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

### 3.3.2 OEMs (vehicle manufacturers and Tier-1 suppliers)

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

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

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

# 4 Publication of the requirements

In the following sections we elaborate further on the previous requirements, this time focusing on how to best convey them to the relevant stakeholders. One method is through holding an open stakeholder dialogue, in which requirements are to be published in specific (standardisation) bodies. Another method, which we deem is more successful on the long term and has the ability to integrate all requirements, is by establishing a so-called codified highway code.

## 4.1 Open stakeholder dialogue

The most straightforward way of being inclusive and assuring that all relevant stakeholders are involved and in agreement, is by introducing all the requirements systematically into the relevant eco-systems. In addition to having one-on-one exchanges with all the various stakeholder groups (as already being done in the TM4CAD workshops, as well as those from previous and current related projects), there is another method to achieve this: by means of (standardisation) bodies. An effective way is then to document and publish the requirements through UNECE / ISO. This can also be seen as a prerequisite step in order to bring the guidelines for our proposed codified highway code to a regulating level.

The added benefit of TM4CAD is that it provides explicit links with distributed ODD awareness, which is directly relevant for road operators, and OEMs in particular. Through the detailed treatment given in the previous WP2-4 related documents, we are able to integrate isolated parts (e.g., ODD taxonomy, infrastructure, etc.) and have them one by one included in standardisation, opening the way to a more broad adoption.

The results from all our open stakeholder dialogues (mainly through our workshops) are already incorporated in the various subsections of Chapter 2.

## 4.2 Codified highway code

### 4.2.1 Concept

To enable the road operators to define *good behaviour* for CAD systems, the next step is the introduction of a novel ODD and ISAD based highway code concept, along with a common set of ODD attributes, in similar spirit as to how a *regular* highway code[1] defines the expected behaviour from human drivers. This will enable manufacturers and road operators to communicate in a common, predefined language, and allow for changes in CAD traffic throughput due to ODD and ISAD changes. This good/expected behaviour of CAD systems will form part of a behaviour library, while operating conditions will be part of (instantiations of) the ODD. The benefit of this is that any ADS, as well as road operators, can adopt and follow these codified 'rules of the road', with them being unambiguous and clear.

This method is already being pushed forward within the UK, based on road authorities' and manufacturers' needs and interests. Simultaneously, this code will encompass expected

[1] A highway code is a set of information, advice, guides, and mandatory rules for road users in a specific country. Its objective is to promote road safety, and it applies to all road users including pedestrians, horse riders, and cyclists, as well as motorcyclists and drivers. It gives information on road signs, road markings, vehicle markings, and road safety. There are annexes on vehicle maintenance, licence requirements, documentation, penalties, and vehicle security. In an international context, a highway code may be follow the treaty set out by the Vienna Convention on Road Traffic.

behaviour in certain operating environments, therefore providing a close link with the ODDs and ISAD levels. In the following, we give some insights into the process of turning the highway code into a more deterministic/mathematical format [DEK22].

Two of the relevant topics for ADS driving safely are:

- The ADS should comply with traffic rules.
- The ADS should interact safely with other road users.

In addition, the ADS should respond in line with traffic laws to markings and signals.

To this end, it becomes paramount to create verifiable requirements that can be used to create relevant scenarios. As an example, consider UK Highway Code Rule #195:

> *"As you approach a zebra crossing: look out for pedestrians waiting to cross and be ready to slow down or stop to let them cross; you MUST give way when a pedestrian has moved onto a crossing."*

In the previous statement, we can make a distinction between behaviour and ODD-related information. However, a crucial question – and currently an assumption – for ADS here is: how long must (the vehicle) wait?

**Current rules of road for human drivers**

**= function(operating condition, behaviour competency, assumptions)**

By applying a rigorous codification process, the aim is to reach:

**Codified rule of the road**

**= function(operating condition, behaviour competency, driving characteristics)**

In the current setup, it is necessary to derive the right set of requirements. For the aforementioned rule, this becomes:

- The speed limit is the absolute maximum and does not mean it is safe to drive at that speed irrespective of conditions. Driving at speeds too fast for the road and traffic conditions is dangerous. You should always reduce your speed when:
    - the road layout or condition presents hazards, such as bends
    - sharing the road with pedestrians, cyclists, and horse riders, particularly children, and motorcyclists
    - weather conditions make it safer to do so
    - driving at night as it is more difficult to see other road users.

In a first step, we identify the different types of information as follows:

- speed limit is absolute maximum and does not mean safe speed
- reduce speed when:
    - road layout or condition hazards, bends
    - sharing the road pedestrians, cyclists, and horse riders, particularly children, and motorcyclists
    - weather conditions make it safer
    - driving at night

Aside from identifying non-informative text, we used the following conventions:

- Behaviour
- ODD
  - Scenery
  - Actor
  - Environment
- Rule/parameter qualifying
- Problematic word use

Finally, the next step is to convert this information into formal logic, as follows:

- isVehicle(x) → speed(x) < limit(speed)
- (near(x,a1) ⋀ ¬isVehicle(a1))
- isVehicle(x) ⋀ (isAtHazard(x) V
  (near(x,a1) ⋀ isPedestrian(a1)) V
  (near(x,a2) ) ⋀ isCyclist(a2)) V
  (near(x,a3) ) ⋀ isHorseRider(a3)) V
  (near(x,a4) ) ⋀ isChildren(a4)) V
  (near(x,a5) ) ⋀ isMotorcyclist(a5)) V
  isUnsafeWeather(env) V
  isNight(tod))
  → action(reduceSpeed)

*(here we used the logical symbols ⋀ and V to denote AND and OR, respectively)*

However, in the previous example we are still confronted with certain essential questions: what does "*near*" mean, what about "*hazard*", what is "*UnsafeWeather*"? Are we defining a vehicle as something that is anything with four or more wheels? What do we mean by "*slow speed*"? What is acceptable? And what to we mean by "*reduceSpeed*"? Answering these questions requires active research, thereby specifically addressing the different ranges of parameter values that can be assigned to these, and then into the consequences of each of these choices. A possible approach to deal with this is to set up (sub)microscopic traffic simulations with dedicated controllers that regulate the car-following and lane-changing behaviour in line with the codified rules, and then assessing the impacts through a wide range of KPIs (including ones for safety, such as time-to-collision, etc.).

The ultimate goal here is then to apply this process and to codify all the Vienna Convention Rules of the Road, as well as the national specifics. These rules by themselves also contain ample statements are left open to interpretation and thus need to be cleared before codification. For example:

- Article 7 (General rules):
  - (3) Drivers shall show extra care in relation to the most vulnerable road users, such as pedestrians and cyclists and in particular children, elderly persons, and the disabled.
  - (4) Drivers shall take care that their vehicles do not inconvenience other road users or the occupants of properties bordering on the road, for example, by causing noise or raising dust or smoke where they can avoid doing so.
- Article 11 (Overtaking):

- (1.4) When overtaking, a driver shall give the road user or road users overtaken a sufficiently wide berth.

For the latter, the codification process would entail first:

- When overtaking, a driver shall give the road user or road users overtaken a sufficiently wide berth.

Which is then turned into the following formal logic:

- isVehicle(x) ∧ onRoad(x,r) ∧
  roadUser(y,r) ∧
  isOvertaking(x,y) ∧
  lateralDistance(x,y,z)
  → sufficientlyWideBerth(z)

A similar article yields the following:

- A vehicle shall not overtake another vehicle which is approaching a pedestrian crossing marked on the carriageway or signposted as such, or which is stopped immediately before the crossing, otherwise than at a speed low enough to enable it to stop immediately if a pedestrian is on the crossing.

All in all, the previous serves to show that it is useful to use ODD-based rules of the road to attain a wider safety assurance. Hence:

- Each rule of the road (anywhere) will always be a function of ODD and behaviour competencies
- Each scenario (irrespective of the system under test), will always have ODD attribute information and behaviour information.

All this information can be mapped using labels/tags.

### 4.2.2 Implementation

It stands to reason that the responsibility for the initial implementation, that is, construction, of a codified highway code, lies with the NRAs, or broader (local) governments. In order to facilitate this in a smooth way, the OEMs should be involved very early on, given that their vehicles will have to work and deal with the code in a wild variety of real-life conditions.

At current, the only known example where this is being done is in a test phase in the UK. Further insights need to be developed, as there is the risk that a codified highway code will not be able to deal with all possible situations on the road. If we assume that the highway code encompasses all known rules for operating a vehicle on the road under all conditions, then there is less of a problem. However, that is based on an assumption, while it is more rational to state that these limited scenarios do not encompass the entire span of possible interactions between vehicles, infrastructure, and any other traffic participant. Only complying with these scenarios would then incur unforeseen risks, where it would be better that a broad testing is foreseen by having NRAs cooperate closely with the OEMs.

# 5 Conclusions

The main objective of this deliverable is to provide a complete set of realistically implementable requirements, from traffic management systems and road operators, to CAD systems and automated vehicle manufacturers.

This entails an on-going collection of requirements, first from a technical point of view (for traffic management and CAD systems), and then highlighting the roles both the national road authorities (and traffic management centres) and vehicle manufacturers (and Tier-1 providers) play in this respect. At the moment, most of the requirements were given at a higher level, based on the work done in WP2, with extra inputs stemming from the MANTRA, EU EIP, and TransAID projects.

In addition, we focused on how to best convey them to the relevant stakeholders. To this end, we hold open stakeholder dialogues through workshops. The next two related steps are then to publish requirements in specific (standardisation) bodies on the one hand, and to establish a so-called codified highway code which has the ability to integrate all requirements on the long term.

**Further work (final D5.1 iteration)**

We will validate the output of WP5 in the sixth workshop (WS6) in November 2022, for an international audience including researchers, road operators, and vehicle manufacturers, presenting:

- The use cases that are specified in WP4
- Requirements to AV manufacturers
- An infrastructure evolution path
- An overview of how the codified highway code works

➔ The aim of the workshop is to pave the way to a more unified and cooperative roadmap.

The consortium already had a workshop together with a subset of the OEMs, in cooperation with the HiDrive project. They will provide us with a list of attributes that are relevant to them, after which we can see how this could fit into this deliverable's recommendations. The publication of these attributes are however planned in October 2022, well after the submission of the current iteration, and will therefore be considered in its final iteration.

All the requirements will then also be categorised with regards to who is responsible for the provisioning of them (e.g., shared data). In that respect it may also be necessary to include a timeline as to when these requirements will become relevant (i.e. short/medium/long term).

In addition, the final iteration of this document will also contain any relevant information captured from the Horizon 2020 Trustonomy, PAsCAL, and SUaaVE projects and DG MOVE's "*Study on the Effects of Automation on Road User Behaviour and Performance*".

As such, the current document will grow into a more or less exhaustive list of requirements that are relevant for any road operator and OEM.

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