Conférence Européenne des Directeurs des Routes

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DROIDS

Digital Road Operator Information and Data Strategy (DROIDS)

Digital twin use cases

Digital transport regulations, opening new roads, automated lane level navigation

Deliverable D3.4 Version 1.1

11th July 2025

FEHRL IFE Institutt for energiteknikk MAP Royal HaskoningDHV TRAFICON WMG THE UNIVERSITY OF WARWICK

CEDR Call 2022 Data: Maintaining and sharing the digital road infrastructure

Digital Road Operator Information and Data Strategy (DROIDS)

D3.4 Digital twin use cases – digital transport regulations, opening new roads, automated lane level navigation

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Executive summary

Digital technologies, particularly the digitization of traffic rules and the deployment of High-Definition (HD) maps, are revolutionizing European road traffic management. Digitizing traffic regulations enables seamless integration with intelligent transportation systems and supports the safe operation of connected and autonomous vehicles (CAVs), while HD maps, with their centimetre-level precision and machine-readable format, provide critical data for advanced driver-assistance systems (ADAS) and automated driving systems (ADS), enhancing perception and localization. Road operators, leveraging Building Information Models (BIM) and Asset Information Models (AIM), can serve as authoritative data providers for these HD maps, facilitating safer and more efficient autonomous transportation.

This deliverable presents the findings of work carried out within task 3.4 and 3.5 of DROIDS project to provide road operators with increased knowledge and support to reap optimal benefits from digitalisation as they evolve to become digital road operators operating the physical, operational, and digital road infrastructures. It aimed to explore the digital representation of traffic rules and regulations and report on two use cases: Reusing BIM/AIM information for HD maps and provision of authoritative information needed for lane level navigation by ALKS.

Scope

This deliverable presents the results of research carried out during the Task 3.4: Digital Twin Use cases. It aims to provide answers to the following DROIDS project Research Questions (RQ):

(RQ12) How can traffic rules and regulations be transformed into a digital and machine-readable representation that enables automated vehicles to understand and follow them on a European level?

(RQ13) To what degree will physical traffic signs, signals and markings be needed in a future of automated driving, where rules and regulations are digital and machine-readable?

(RQ14) How can dynamic [regulation] information be described and shared with road users, in combination with the more static regulations?

Methodology

This report consolidates findings from Tasks 3.4 and 3.5 of the DROIDS project, focusing on the digital representation of traffic rules and the flow of information for automated transport. For Task 3.4, a comprehensive literature review, building upon previous CEDR projects, was conducted, followed by a stakeholder workshop and questionnaire to gather insights on road operator priorities and roles in traffic rule digitization. These inputs, alongside feedback from an Advisory Group meeting, were analysed to inform the deliverable. Task 3.5 explored two use cases: the integration of BIM and AIM data into HD maps, utilizing literature review and expert brainstorming, validated through interviews with HD map providers; and the information requirements for automated lane-level navigation, combining literature review with a deep dive into legal aspects and alignment with DROIDS deliverable D2.2.

Digital representation of traffic rules and regulations

Digitization of traffic rules and regulations means bringing the content of the traffic rules into a machine-readable format which could be utilised for a variety of digital applications including use within ADS.

This deliverable explored various traffic rule digitisation initiatives. **Management of Electronic Transport Regulations (METR)** emerged as one of the most relevant standardisation efforts currently being made to digitise traffic rules and regulations. METR enables provision of traffic rules and regulations that machines can understand and trust.

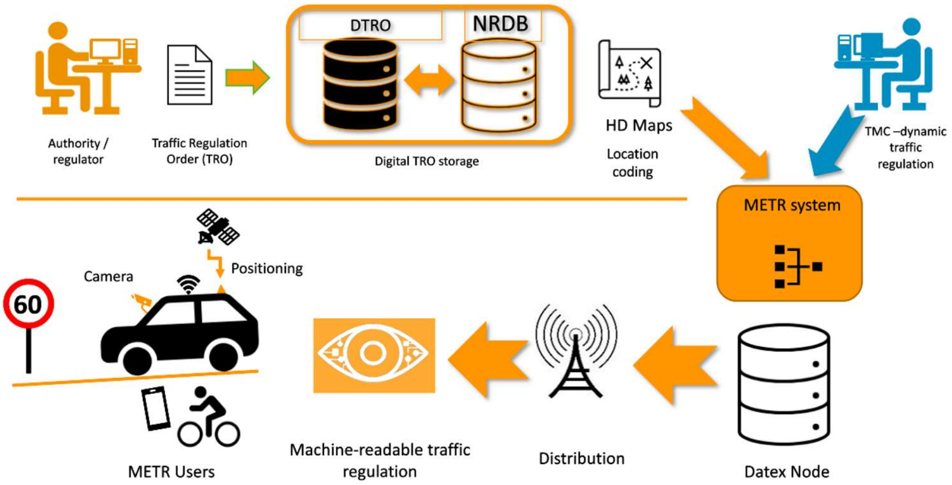

Figure 1: METR process

Figure above illustrates the METR system's process for digitizing traffic rules and regulations, as presented in an NPRA webinar. It encompasses two primary workflows: the digitization of Traffic Regulation Orders (TROs), where issued TROs are converted into a digital format and stored in a database linked to national road data and HD maps, representing static regulations; and the provisioning of dynamic traffic regulations, issued by traffic management centres. The integration of these static and dynamic regulations constitutes the complete METR system which can be safely distributes to METR users.

Priority of rules for digitisation

In order to gain an understanding of traffic rules and regulations deemed important for digitisation by road operators, we asked workshop attendees and questionnaire respondents which rules or regulations would they like to see digitised and in what priority.

Figure 2: Priorities of various traffic rules and regulations for digitisation as indicated by stakeholders

Figure 2 provides an overview of various traffic rules and regulations and their priorities for digitisation. The rules which were indicated as high priority by at least 3 stakeholders are bold and underlined.

The above prioritisation was made in focus to achieve the strategic goals on traffic safety and traffic flow. Road operators also mentioned that their focus currently is currently on implementing the delegated regulations on Safety-Related Traffic Information (SRTI) & Real-Time Traffic Information (RTTI), and SSTP Delegated Regulation as per ITS directive . These rules are relevant for ADS as it can help them determine the legally allowed behaviour inside their ODD.

Roles of stakeholders in traffic rule digitisation

A role analysis was carried out during the workshop and advisory group meetings to discuss the role of various stakeholders in the ecosystem focussed more towards the role of road operators. Table 9 presents the outcome of role analysis carried out.

Road operators play a multifaceted and crucial role in the lifecycle of digital traffic rules and regulations. They are actively involved in issuing traffic regulation orders, adapting national and regional standards, and provisioning up-to-date, high-quality data for end users during the operational phase. They also contribute to the maintenance of traffic rules and regulations and provide input to ensure standards accommodate local interests. Their activities span from the initial stages of standardisation and digitisation to the ongoing operation and maintenance of the digital traffic ecosystem.

Future of physical signs and markings

Despite advancements in digital technologies like HD maps and machine-readable regulations, physical traffic signs, signals, and markings remain essential for safe navigation in the foreseeable future. This necessity stems from the current reliance on traditional infrastructure, the coexistence of human-driven and autonomous vehicles, incomplete HD map coverage, and ongoing standardization efforts for digital traffic rules. Physical infrastructure also addresses limitations in camera-based detection and supports innovation, while the gradual phasing out of human-driven vehicles underscores the continuing importance of these elements for maintaining road safety and order.

Use case 1: Reusing BIM/AIM information in HD-maps

High-Definition (HD) maps are machine-readable and centimetre level precise digital representation of the physical infrastructure that can be used by the cooperative, connected, and automated mobility (CCAM). These maps are not intended for general navigation by human drivers but are specifically designed for machines, serving as a detailed and precise representation of the physical world.

This deliverable dived deeper into various technical details about the HD maps. First growth and adoption of HD maps was studied. Furthermore, HD maps was described with the help of various layered architectures. The creation process of HD maps was highlighted and a commentary on maintenance of HD maps was made.

Furthermore, a framework for BIM information reuse in HD maps was adapted and proposed (Figure 3). In this framework, Road operators standardize data using OTL, providing validated BIM information to HD map providers, either directly or via a National Access Point (NAP), and incorporating asset management data. HD map providers enrich their maps with this BIM/AIM data, reducing the need for extensive on-road data collection. A feedback loop from vehicle-generated data allows for the correction of discrepancies between digital information and physical infrastructure, demonstrated by projects like ROMO, where vehicle sensor data is used to enhance asset management and road condition monitoring. This integration aims to improve the accuracy and efficiency of HD maps for connected and automated vehicles (CCAVs).

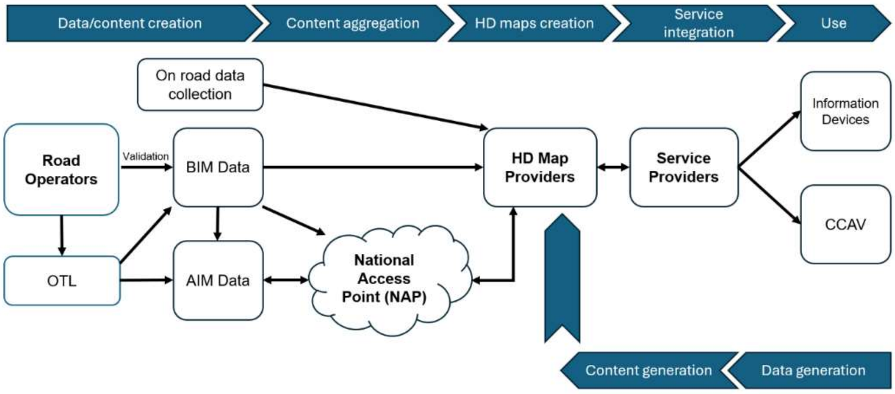

Figure 3: HD map process flow diagram adapted from Radics et al. 2020 for BIM information reuse

This use case explored the feasibility of utiising BIM and AIM data to streamline the creation and maintenance of HD maps, aiming to reduce the reliance on costly, dedicated data capture. Through a literature review and collaborative brainstorming, the use case adapted the standard HD map creation process to incorporate BIM/AIM data, mapping relevant BIM/AIM elements to the base, geometric, and semantic layers of HD map architecture. The findings indicated significant potential for BIM/AIM to enhance HD map accuracy and facilitate efficient updates, particularly when AIM is integrated to ensure continuous synchronization.

However, the use case also identified critical challenges related to the quality, compatibility, and reliability of existing BIM data provided by road operators. HD map providers expressed concerns about the current state of this data, highlighting the need for improved standardization and validation. The implementation of object type library (OTL) standards within BIM/AIM processes was recommended to address these issues, ensuring data consistency and understandability. Furthermore, secure data exchange through National Access Points (NAP) and feedback loops from vehicle sensors were proposed as mechanisms to validate and refine the BIM-derived HD map data, ultimately improving overall accuracy and reliability.

Use case 2: Authoritative information for ALKS

Automated Lane Keeping Systems (ALKS) is a vehicle technology engineered to manage both the lateral (steering) and longitudinal (acceleration and deceleration) movements of a vehicle over extended periods without continuous input from the driver. This use case provides an analysis of the critical elements necessary to ensure the safe and legal operation of Automated Lane Keeping Systems (ALKS).

ODD of ALKS

The Operational Design Domain (ODD) defines the conditions under which ADS can safely operate. It sets the boundaries, specifying environmental conditions, road types, and other factors where the autonomous system is designed to function. Complexity of traffic environment could limit the performance of ADAS systems due to ODD limitations. Several challenging road situations for ALKS were identified as:

- Urban environments with presence of pedestrians, cyclists, intersections, roundabouts, etc.
- Construction zones with reduced lane widths, temporary and unclear lane markings
- Adverse Weather Conditions such as snow, fog, rain, ice etc
- Complex interchanges and merging lanes such as entry/exit from motorway, lane drops etc.
- Tunnels which can degrade GPS signal and present variation in lighting conditions
- Emergency vehicles where ALKS must react appropriately to allow them to pass.

Regulatory landscape for ALKS

UN Regulation No. 157 is the primary EU regulatory framework for ALKS, establishing technical requirements and testing procedures for vehicle type approval. The regulation sets conditions for ALKS activation, including driver availability, suitable road and environmental conditions (initially highways with a central barrier, no pedestrians/cyclists), and operational status, with recent amendments increasing the maximum speed to 130 km/h and expanding functionality. Vehicles must be equipped with a Data Storage System for Automated Driving (DSSAD) to record system activity and collisions and include Driver Availability Recognition Systems that monitor the driver's readiness to take control, issuing warnings and transition demands as needed. ALKS must allow for easy driver override and provide clear operational status warnings, including performing a minimum risk maneuver if the driver doesn't respond to transition demands. Compliance with UN Regulations on cybersecurity (UN R155) and software updates (UN R156) is also required, and the type approval process includes virtual simulations, closed-track testing, and public road driving tests.

Digital Information requirements for Lane-Level Navigation

This use case investigated the authoritative information needed for automated lane level navigation by ALKS. Lane-level navigation for automated vehicles, particularly ALKS, requires authoritative digital information from trusted sources like road authorities. This information, encompassing road types, geographic areas, speed ranges, environmental conditions, and object/event detection, is crucial for safe operation. While sensor-based systems can perceive some data, comprehensive ODD attributes, as defined by BSI PAS 1883 and ITS directives, necessitate robust digital maps and real-time traffic updates. These maps, despite advancements, face challenges in coverage, accuracy, and maintenance. National Access Points (NAPs) facilitate data accessibility, emphasizing security, privacy, and data quality. Road operators play active roles in developing, operating, and ensuring the quality of this information, adhering to European standards and regulations, to support reliable and interoperable automated driving systems.

DROIDS project description

DROIDS is a CEDR Transnational Road Research Programme Call 2022 project aiming to provide the road operators, including European National Road Authorities (NRAs), increased knowledge and support to reap optimal benefits from digitalisation as they evolve to become digital road operators operating the physical, operational and digital road infrastructures. As digital road operators, the road operators will provide better road user services while improving road transport's safety, efficiency and sustainability.

The background of the research is the ongoing transformation of the road operators to digital road operators responsible for operating both the physical and digital road infrastructure. Some road operators have already developed their processes and services accordingly, while some are still reflecting on the developments and discussing the transformation.

First the project will look at the evolving roles of the road operators as they transform themselves into digital road operators. Special focus is given to new roles brought by digital road operation while changes foreseen about the existing roles are addressed. DROIDS pays specific attention to the role evolution in different CEDR member countries with currently varying roles and digital maturity.

Secondly, the project studies the evolution of digital twins from road data banks to comprehensive real-time digital twins of the road transport system, including the infrastructures, traffic, land use, road environment etc. Here, the integration of the digital twins with the processes in the road operator's core business and tasks is assessed in a thorough manner.

Thirdly, trust has been identified as the key attribute for road operator originated data/information concerning its use by private sector stakeholders such as vehicle manufacturers and service providers. Thereby DROIDS also highlights the issues related to ensuring trust and security in the maintenance, sharing, and use of the digital road infrastructure.

Finally, the work of DROIDS concludes in the production of an overarching data strategy for the physical and digital road operators taking on board the results from DROIDS and other ongoing projects (such as the CEDR Data Call 2022 PRESORT and TIARA projects).

Expected achievements and benefits to road operators:

- DROIDS offers road operators a clearer understanding of the prerequisites and roles associated with becoming a digital road operator, vital for road operators considering this transition.
- It emphasizes the crucial step for road operators: adapting processes to maximize benefits from digital tools.
- While DROIDS provides insights for process adaptation, the actual implementation must align with each road operator’s unique digital and organizational maturity.
- The project results will outline specific recommendations regarding actions and roles tied to HD maps, electronic traffic, and transport regulations, aiding road operators in decision-making.

Glossary

AG	Advisory Group
ADS	Automated Driving Systems
ADAS	Advanced driver-assistance systems
AIM	Asset information modelling
ALKS	Automated Lane Keeping Systems
AWV	Agentschap Wegen en Verkeer (Belgium)
BIM	Building Information Modelling
CAV	Connected and autonomous vehicles
CCAM	Cooperative, Connected, and Automated Mobility
CDE	Common data environment
CEDR	Conference of European Directors of Roads
COBie	Construction Operations Building Information Exchange
CoDEC	Connected Data for Effective Collaboration project funded by CEDR
DATEX	DATa EXchange between traffic and travel information centres
DROIDS	Digital Road Operator Information and Data Strategy project funded by CEDR
DSSAD	Data Storage System for Automated Driving
DT	Digital Twin
DTM	Digital Terrain Model
DTF	Digital Transformation Framework
EC	European Commission
EU	European Union
FTIA	Finnish transport infrastructure agency
GPS	Global Positioning System
HD	High Definition
IFC	Industry Foundation Classes
INTERLINK	INformation managemenT for European Roads using LINKed data project funded by CEDR
ISO	International Organization for Standardisation
ITS	Intelligent Transport Systems
IoT	Internet of Things
n.d.	No date mentioned in the reference

METR	Management of Electronic Traffic Regulations (METR)
NRA	National Road Authority. NRA is often used in Europe. This study uses a term “road operator” that also includes NRAs.
NAP	National Access Point
ODD	Operational Design Domain
OTL	Object Type Library
PIM	Project information model
ROMO	Road Monitoring
RWS	Rijkswaterstaat, the Netherlands
RTTI	Real-Time Traffic Information
SRTI	Safety-Related Traffic Information
TEN-T	Trans-European Transport Network
TRO	Traffic Regulation Orders
TII	Transport Infrastructure Ireland
UN	United Nations
UVAR	Urban Vehicle Access Regulations
VRU	Vulnerable road users

Content

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1 Introduction

Digital technologies offer a potential for improving road traffic management in Europe. From sophisticated data analytics to real-time communication systems, digital tools can enhance the efficiency, safety, and environmental impacts of road networks. Among the various facets of this digital transformation, the digitisation of traffic rules and regulations stands out as a critical enabler. By converting traditional, often paper-based, legal instruments into digital formats and integrating them with intelligent transportation systems, road operators can unlock significant benefits. This shift is particularly pertinent as emerging technologies like connected and autonomous vehicles (CAVs) require access to reliable and machine-readable traffic regulations to operate safely and effectively. The traditional understanding of driving, upon which current traffic regulations are built, is fundamentally being challenged by technologies like autonomous driving. This necessitates a re-evaluation and digitisation of these rules to ensure their continued relevance and effectiveness in a rapidly evolving transportation landscape.

On the other hand, High-Definition (HD) maps, characterized by their centimetre-level precision and machine-readable format, are emerging as a cornerstone technology for cooperative, connected, and automated mobility (CCAM). Unlike traditional navigation maps designed for human drivers, HD maps provide a detailed digital representation of the physical infrastructure, encompassing critical elements such as road geometry, markings, traffic signs, and real-time dynamic data. These maps, when integrated with vehicle sensors, enable advanced driver-assistance systems (ADAS) and automated driving systems (ADS) to achieve enhanced perception, precise localization, and contextual awareness, ultimately contributing to safer and more efficient autonomous driving. As the automotive industry progresses towards higher levels of automation, the adoption and geographical coverage of HD maps are rapidly expanding, highlighting their role in realizing the future of autonomous transportation. The road operators could act as an authoritative data provider for HD maps as they could utilise and reuse information from Building Information Models (BIM) and Asset Information Models (AIM) systems.

This deliverable aims to provide a comprehensive analysis of the digitisation of traffic rules and regulations from the perspective of a European road operator. It will delve into the categorisation of these rules, assess their potential for digitisation, define the crucial role of road authorities in this process, and explore existing digitisation initiatives across Europe including Management of Electronic Traffic Regulations (METR). Furthermore, the report dives deeper into two use cases. First, flow of information from BIM systems that record information of the roads as asset to, HD Maps in the vehicles for new road sections to prepare the (new)digital + physical infrastructure for automated transport. Second, provision of authoritative information needed for automated lane-level navigation to ensure automated vehicles navigate legally through complex traffic environments.

The report is structured as follows. Chapter 2 explains the purpose and scope of the deliverable. Chapter 3 introduces the methodology of the study and project as well as the research methods used. Chapter 4 dives deeper into the digital representation of traffic rules and regulations. Chapter 5 reports on the findings of two use cases: HD maps and authoritative information for ALKS. Chapter 6 concludes the findings of this deliverable.

2 Purpose and scope

The DROIDS project aims to provide road operators, including European National Road Authorities (NRAs), with increased knowledge and support to reap optimal benefits from digitalisation as they evolve to become digital road operators operating the physical, operational, and digital road infrastructures.

This deliverable presents the research results carried out during the “Task 3.4: Digital representation of traffic rules and regulations” within Work Package 3 of DROIDS. In this task, the focus lies on understanding how traffic rules and regulations can be transformed into digital and machine-readable formats. It also explores various stakeholders' role in traffic rule digitisation. Furthermore, this deliverable also reports two use cases within “Task 3.5: Report on proof of concepts”.

This deliverable answers the research questions as in Table 1 below. The main research questions are also broken down in sub-research questions.

Table 1: DROIDS project Task 3.2 research questions and related research questions which of the latter are addressed in this deliverable.

DROIDS Task 3.4 research question	Deliverable Chapter
(RQ12) How can traffic rules and regulations be transformed into a digital and machine-readable representation that enables automated vehicles to understand and follow them on a European level?	4
(RQ13) To what degree will physical traffic signs, signals and markings be needed in a future of automated driving, where rules and regulations are digital and machine-readable?	4
(RQ14) How can dynamic [regulation] information be described and shared with road users, in combination with the more static regulations?	4

In addition to answering the task 3.4 research questions, this deliverable also intends to report on two use cases mentioned in task 3.5 as follows:

- **Use case 1:** Flow of information from BIM systems that record information of the roads as asset to, HD Maps in the vehicles for new road sections to prepare the (new)digital + physical infrastructure for automated transport.
- **Use case 2:** Provision of authoritative information needed for automated lane-level navigation to ensure automated vehicles navigate legally through complex traffic environments.

The **Scope of this research** is extracted from the expected results of DROIDS Work Package 3, “Digital Twin application evolution”, as presented in Table 2 below.

Table 2: DROIDS project Work Package 3‘s expected results and the scope of this deliverable.

DROIDS WP3 expected end results	Deliverables
ER1.1 - Building on results of WP2, The state of the art. (technical and functional aspects)	D2.1 & D3.1 (combined report)

ER1.3 - How the information should be maintained and made available for maintenance contractors, map producers and road users throughout the lifecycle of the road infrastructure. (technical and functional aspects)	D3.3
ER1.4 - Considerations regarding standards and standardisation processes and the expected level of complexity for the data.	D3.2
ER1.5 - Requirements for digital representation of traffic rules and regulations, including the need for a physical representation of restrictions in the future and the potential for improved utilization through more dynamic regulations.	This deliverable (D3.4) Chapter 4
ER4 - Report describing proof of concepts: A possible flow of information from BIM to HD Maps for new road sections to prepare the digital infrastructure for automated transport in parallel with the opening of the physical infrastructure	This deliverable (D3.4) Chapter 5
ER5 - Report describing proof of concepts: Provision of authoritative information needed for automated lane-level navigation to ensure automated vehicles navigate legally through complex traffic environments	This deliverable (D3.4) Chapter 5

This deliverable's results provide the basis for the next phases and work packages knowledge creation in the DROIDS project, i.e., input for further research and analysis.

Key terminology

1. It is to be noted that **the term "road operator"** is used in this deliverable to describe any public or private entity that is responsible for the planning, maintenance and management of the road, including management of traffic flows. The term "road operator" therefore also covers road authorities that are public authorities responsible for similar tasks. The term has been here adapted from the European Commission delegated regulation (EU) 2022/670 of real-time traffic information services (EC 2022). The term NRA is often used in Europe to describe a Member State national authority that is responsible for the previously mentioned tasks; in this study, the term road operator is also used to cover NRAs.
2. While the concept of Digital Twin has numerous definitions, the **DROIDS definition of Digital Twin** was formulated which is as follows:

   "**Road transport Digital Twin** is a realistic virtual representation of the real-world physical road transport systems. The road transport Digital Twin can include, depending of a purpose and defined functional scope, digital representation of elements such as road infrastructure, traffic with vehicles and pedestrians, road environment, traffic regulations and restrictions as well as land use. The road transport Digital Twin has a bidirectional real-time data connection between the physical and the digital representation. It can support road operator decision making with dynamic monitoring, analysis, and predictive modelling capabilities of the road transport systems that enable road operators for instance to enhance traffic flow, road safety, infrastructure asset management and sustainability or to facilitate automated driving or other future purposes. "

   The DROIDS definition of Digital Twin will be iteratively reviewed throughout the project based on input and feedback from the project stakeholders. Therefore, the above-mentioned DT definition can be changed in later (DROIDS) deliverable reports. The final definition will be published in the final report (Data Strategy).

3 Methodology

The study's initial research questions and expected results were derived from the CEDR funding call of Data Call 2022, which were then formalised in the DROIDS project proposal's project plan. The scope of the study was limited in the CEDR Call and DROIDS project proposal to a qualitative assessment of digital twin state-of-the-art. The research questions were iteratively reviewed together with the project team as the research work progressed. During the research question reviews it was evaluated what background information and knowledge would be required from the study that would later benefit the next deliverables and stages of the project, and therefore, the final results of the project, i.e., the National Road Authorities Data strategy.

The DROIDS project has also been working with digital twin taxonomy, the first development cycle of which was synchronized with this deliverable. The aim of the taxonomy development was to ensure the use of common definitions of key concepts and terms, such as digital twin, and language throughout the project. The taxonomy was reviewed by external partners of CEDR road authorities and the DROIDS Advisory Group. The latter included public authorities, universities, research centres and private industry members such as service providers.

Project Methodology

The DROIDS project utilises the DTF structured approach that supports the design, development, planning and management of necessary organisational transitions. The DTF adopted for the DROIDS project is illustrated in Figure 4. Within the DTF, it is important to ensure vertical and horizontal alignment between the different columns and layers.

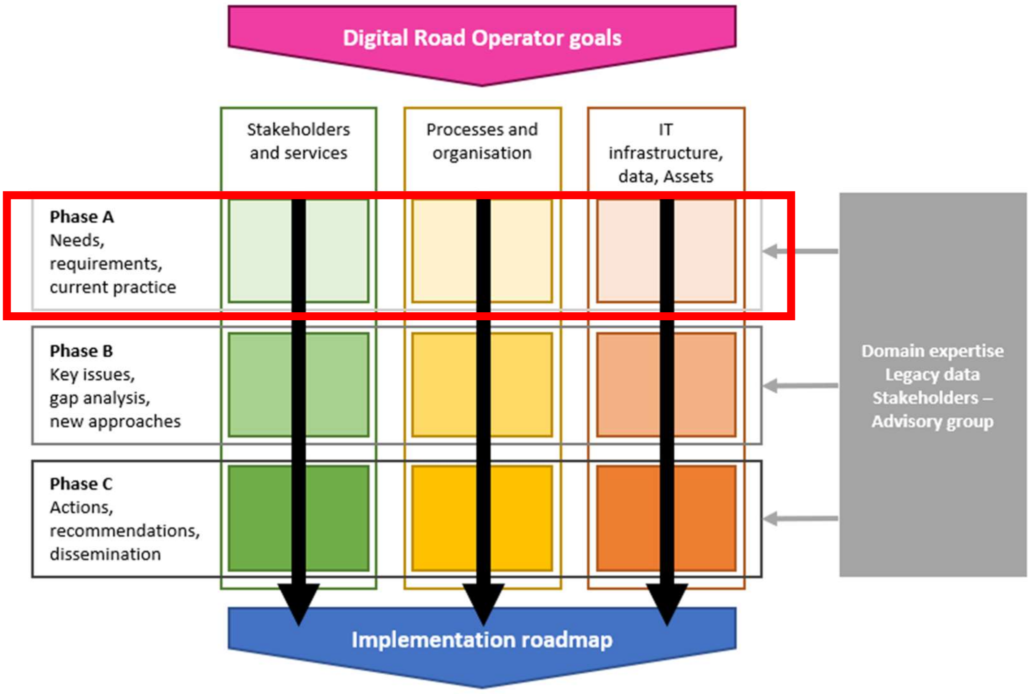

Figure 4 DROIDS project's Framework

Vertical Alignment: This refers to the strategic alignment between requirements, gaps, and actions to fill these gaps, which form the three phases of the project. It follows a top-to-bottom approach, translating overall goals into relevant business cases and roadmaps. The information gained in one layer supports the content creation in the layer below, ensuring a consistent way of achieving the business cases, overarching strategy, and implementation roadmap.

Horizontal Alignment: This ensures completeness by not focusing only on technology or stakeholders but also considering other important organizational factors. It ensures alignment between stakeholders, core business, internal processes, and IT for an organization. This alignment produces the expected outputs holistically and is taken into account in the individual work packages. It pays special attention to alignment with key stakeholders.

This deliverable is a part of the first horizontal DTF Phase A that determines needs, requirements, and current practices as highlighted by a red box in the Figure 4.

Research Methodology

This deliverable presents the outcome of both task 3.4 and task 3.5 within the work package 3 of DROIDS. Within task 3.4: digital representation of traffic rules and regulations, a desk research on the current state of the art of traffic rule digitisation was carried out. The literature review included analysing the outputs from previous CEDR projects: TM4CAD and DiREC. Based on the findings from the literature review and identified gaps, a workshop with various road operators was conducted to gather information on the priorities of road operators and roles of various stakeholders in traffic rule digitisation. Furthermore, a questionnaire with similar content as workshop was shared to gather more responses from stakeholders who could not attend the workshop. The outcome of the analysis of inputs from workshop and questionnaire was presented at the Advisory Group (AG) meeting to gather more inputs and feedback on the findings. The outcome of all inputs from workshop, questionnaire and AG meeting are analysed and presented in this deliverable.

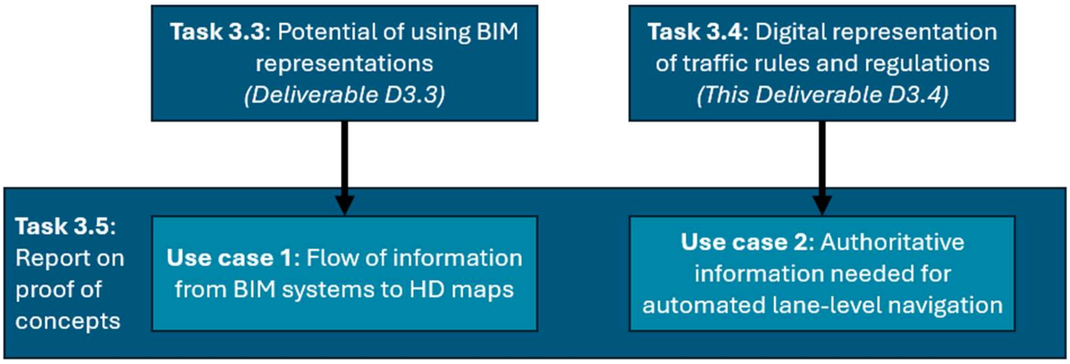

Figure 5: Relationship between various tasks and use cases

On the other hand, the task 3.5 is focused on reporting on two use cases. The first use case focus on flow of information from BIM and AIM systems to HD maps for automated transport. For this use case, the inputs from DROIDS deliverable D3.3 regarding BIM information reuse was utilised as a starting point. A literature review on the HD maps was carried out to understand the underlying mechanism, architecture and explore potential opportunities of BIM information reuse. Based on the findings from literature review, a brainstorming session was conducted with the experts in Royal HaskoningDHV to adapt the framework and process flow diagram of HD maps creation and use towards BIM information reuse. In addition, Interviews with HD maps providers was conducted to validate the framework and gather additional details from a service provider's perspective,. This use case was further aligned with DROIDS work package 5: Data Strategy.

The second use case focus more on the information needed for automated lane level navigation by ADS with focus on traffic rules and regulations. This use case is related to task 3.4: digital representation of traffic rules and regulations. In this use case, first a literature review was conducted to first understand the functioning and Operational Design Domain

(ODD) of (A)LKS. Furthermore, a deep dive study was carried out to understand the legal aspects around automated lane keeping and information requirements for safe lane level navigation. The collected information was thus analysed in coordination with DROIDS deliverable D2.2: NRA roles in digital twin, bringing the insights from NRA roles into the use case.

Literature review methodology

A literature review was conducted related to digital representation of traffic rules and regulations where previous CEDR projects: TM4CAD, MANTRA, and DiREC was used as a starting point. The research was then conducted around the main and sub research questions to gather relevant information. Furthermore, from the identified resources, snowballing was carried out to identify more relevant literature. In addition, any information shared by the stakeholders via workshop, questionnaire or during interaction such as AG meetings, consortium meetings, collaboration meetings etc. was also used.

Workshop methodology

To gather the inputs from Road Operators regarding the traffic rule digitisation, a workshop was conducted on 18th November 2024. The workshop was attended by representatives from various road operators as shown in Table 3. The workshop focussed on gathering the priorities of road operators for traffic rule digitisation and discuss their role in the ecosystem. The content of the workshop and responses are shared in Appendix A.

Table 3: An overview of organisations who were present at the workshop

Organisation	Type	Country
Danish Road Directorate (Vejdirektoratet)	NRA	Denmark
Rijkswaterstaat (RWS)	NRA	Netherlands
TII	NRA	Ireland
AWV	NRA	Belgium
Transportstyrelsen - Swedish Transport Agency (STA)	NRA	Sweden

Questionnaire methodology

To gather additional inputs from stakeholders who could not participate in the workshop, a questionnaire which contained similar questions was circulated to the to additional stakeholders. The content of questionnaire can be found in Appendix B. A total of 7 responses were received via questionnaire from the following organisations:

Table 4: An overview of organisation who responded via questionnaire

Organisation	Type	Country
Intelligent Transport Systems	Transport authority	Romania
Traficon	Consultancy	Finland
Danish Road Directorate (Vejdirektoratet)	NRA	Denmark
AlbrechtConsult	Consultancy	Germany
Norwegian Public Road Administration (NPRA)	NRA	Norway
National Highways	NRA	UK
Federal Roads Office FEDRO	NRA	Switzerland

Inputs via AG meeting

An advisory group meeting was conducted on 6th Dec 2024 where inputs from various advisory group members regarding traffic rule digitisation and role of road operators was gathered.

4 Digital representation of traffic rules and regulations

This chapter aims to provide state of the art around digital representation of traffic rules and regulations and sheds light into the priority information for digitisation within DROIDS task 3.4.

4.1 State of the Art

4.1.1 Traffic rules and digitisation

Traffic rules are the backbone of safe vehicle operation. Legislation and traffic rules concerning traffic and movement are based on international (UNECE) agreements. The Vienna convention on road traffic signed in 1968[1] established standard traffic rules among the participating countries to facilitate international road traffic and improve safety. Since 2021, a definition of automated driving system is introduced in article 1 of convention on Road Traffic[2]. This addition of automated driving systems in general traffic rules boosted the ongoing efforts towards digitalisation of traffic rules and regulations.

Digitization of traffic rules and regulations means bringing the content of the traffic rules into a machine-readable format which could be utilised for a variety of digital applications including use within ADS.

Digital technologies hold the key to revolutionizing road traffic management, promising enhanced efficiency, safety, and environmental sustainability. From advanced data analytics to real-time communication, these tools can optimize road network performance. A crucial aspect of this transformation is the digitization of traffic rules and regulations. By converting traditional, paper-based legal documents into digital formats and integrating them with intelligent transportation systems, road operators can realize substantial advantages. This shift doesn't only help human drivers in preventing accidently breaking the rules but also is especially vital for the seamless and safe operation of emerging technologies like ADS, which rely on reliable, machine-readable traffic regulations.

ADS rely on sensor data and detailed maps for navigation. Their driving decisions are made through a three-stage process as indicated by Robert Yen (n.d.):

Perception: The vehicle analyses its surroundings, identifying traffic signals, objects (stationary and moving), and their types (buildings, cars, pedestrians, etc.). It also determines its own location and measures the distance, direction, and speed of surrounding objects.

Prediction: The system forecasts potential future behaviours of each detected object.

Planning and Control: Using map information and the data from the perception and prediction stages, the vehicle plans its route and executes driving commands, adhering to traffic regulations.

The digital traffic rules and regulations form a basis for the driving decision in third step Planning and Control for ADS.

The digitalisation of traffic rules also presents new opportunities and regulatory challenges. For example, current rules and regulations held human drivers liable to ensure rules are followed. With digital traffic rules and regulations, for higher level of autonomy, it would become

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[1] https://treaties.un.org/doc/Treaties/1977/05/19770524%2000-13%20AM/Ch_XI_B_19.pdf

[2] https://unece.org/transport/documents/2021/01/reports/report-global-forum-road-traffic-safety-its-eighty-first

essential to determine if the vehicle manufacturer or users should be liable for driving decisions made by the software (*Digitalization in Road Traffic - IETL Institute for European Traffic Law*, 2024).

The traditional understanding of driving, upon which current traffic regulations are built, is fundamentally being challenged by technologies like autonomous driving. This necessitates a re-evaluation and digitisation of these rules to ensure their continued relevance and effectiveness in a rapidly evolving transportation landscape.

4.1.2 Category of traffic rules and regulations

The European Union framework encompasses "Road rules and safety" as a distinct legal area, further divided into national rules and traffic offences. While some fundamental rules, such as the mandatory use of seat belts and child restraints, and the prohibition of using a mobile phone without a hands-free set while driving, are applied across all EU countries, significant national variations exist. These differences include maximum blood alcohol levels, speed limits for various road types and vehicles, required safety equipment, the mandatory use of daytime running lights and/or winter tyres, and even the side of the road on which driving occurs. This interplay of harmonised and divergent rules underscores the complexity faced by European road operators managing infrastructure used by a diverse population of drivers (*Road Rules and Safety - Your Europe*, 2022).

This section sheds light into different traffic rules and regulations that a driver must take care of during normal driving conditions. We also categorised these rules as dynamic i.e., these rules can change in certain conditions and digitizable i.e., it can be transformed into machine readable format that can be followed by AVs. The Table 5 presents various traffic rules categorised into five categories. The list of traffic rules is extracted from various sources including driving theory books (Vekabest, 2025). Please note that this list is not exhaustive and there might be more relevant traffic rules and regulations in place.

Table 5: Various traffic rules and their digitisation potential

Category	**Rule**	**Dynamic**	**Digitization potential**
Operational traffic rules	Speed limit	X	High
	Lane usage (e.g., Hard shoulder running)	X	High
	Overtaking rules (e.g., overtaking on right of block markings)		High
	Access restrictions (UVAR)		High
	Entry/Exit/roundabouts rules		High
	Priority to other road users (including VRUs)		High
	Boarding and Alighting passengers		High
	Signalling/Indicator rules		High
	Parking	X	High
	Reversing / U-turn		High
	Hazard warning lights		High
	Obstacle/road narrowing related rules		High
Vehicle and	Driver License		Med

Driver compliance	Seat belt		Med
	Child safety system		Low
	Phone usage		Med
	Driving under influence		Low
	Winter tyres		Low
	Vehicle lights		Low
	Trailer		Low
	Towing		Low
	Red warning lights in car's dashboard		Low
	Load protrusion		Low
Road Signage, Signals, and Markings	Traffic signal	X	High
	Traffic signs • Speed (mandatory and recommended) • Right of Way (e.g., priority in intersections) • Closed roads • Direction (e.g., roundabout, one way road etc.) • Parking and waiting • Mandatory and prohibitive (e.g., no overtaking) • Type of road (e.g., motorway, pedestrian path etc.) • Warning signs (e.g., animal crossing) • Route directions • Information panels (e.g., number of lanes, end of lane etc.)		High
	Dynamic route information panels (DRIP)	X	High
	Road markings (Priority, turning, BUS lane etc.) • Solid line • Broken line • Bus lanes • Warning lines • Hatchings • Temporary road markings • Turning arrows • Priority symbols (shark teeth)		High
	Zones (school, residential etc.)		High
Rules for Specific Road User Groups	Height restrictions (HGV)		Med
	Weight restrictions (HGV)		Med
	Overtaking Ban HGV	X	High
	Disabled road users		Low

	Hazardous good restrictions		High
Temporary and Conditional Traffic Regulations	Roadworks	X	High
	Incidents / Breakdown	X	Med
	Road closure	X	Med
	Emergency vehicles		High
	Funeral procession		Med
	Military convoy		Med
	Weather / Visibility rules	X	Low

Assessing the digitisation potential of each category of traffic rules requires considering factors such as the clarity and codification of the rules, the availability of relevant data, the potential benefits of digitisation for safety and efficiency, the technical feasibility of implementation, and the value for connected and autonomous vehicles.

Rules related to the operation of vehicles dictate how vehicles should be driven, including speed limits, lane discipline, overtaking, and right-of-way at intersections. **Operational Traffic Rules** exhibit high digitisation potential. Speed limits, for instance, can be dynamic, adjusting based on real-time weather or traffic conditions. The speed limits are already being digitised after the mandate of ISA systems in cars sold from July 2024[3]. Lane usage can also be dynamic for example hard shoulder running during peak hours which can be monitored using sensors, and right-of-way rules can be integrated into the operating systems of autonomous vehicles.

Regulations concerning vehicle requirements and standards specify the legal obligations for vehicles and their drivers, such as registration, licensing, and mandatory safety equipment. **Vehicle and Driver Compliance Regulations** have low-moderate digitisation potential since many rules are related to physical elements or require physical intervention. While physical or secure digital verification of documents may still be necessary, the rules themselves can be embedded in digital checklists and enforcement systems. Real-time database checks are also feasible. Several rules such as phone usage[4] and seat belt[5] are already enforced with the help of cameras in infrastructure.

Rules pertaining to road infrastructure and signage govern the design and interpretation of traffic signs, road markings, and signals. **Road Signage, Signals, and Markings** offer high digitisation potential. Digital representations of road signs are crucial for ADAS and autonomous driving since it often defines the permissible behaviour on roads. Similarly, road markings also such as type of lane marking, priority and yielding signs are also crucial for driving safety as it also defines permissible driving manoeuvres.

Specific rules for different types of vehicles and road users, like HGVs, address their unique needs and potential impacts. **Rules for Specific Road User Groups** present moderate potential. Some rules, like weight, height restrictions for HGVs, can be digitally enforced. However, rules concerning vulnerable road users often rely on driver awareness. Dynamic

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[3] https://road-safety-charter.ec.europa.eu/resources-knowledge/media-and-press/intelligent-speed-assistance-isa-set-become-mandatory-across

[4] https://etsc.eu/netherlands-to-install-more-cameras-to-detect-mobile-phone-use-at-the-wheel/

[5] https://etsc.eu/new-spanish-safety-cameras-to-detect-seat-belt-use/

overtaking bans for HGVs represent a digitisation opportunity within this category.

Regulations concerning temporary traffic management are enacted for specific situations like roadworks or events. **Temporary and Conditional Traffic Regulations** have high digitisation potential. Information about roadworks, closures and incidents can be disseminated in real-time through digital channels which could help both human drivers and ADS. Rules around special vehicles such as emergency vehicles, military convoy, and funeral procession are a bit different and thus indicate medium digitisation potential.

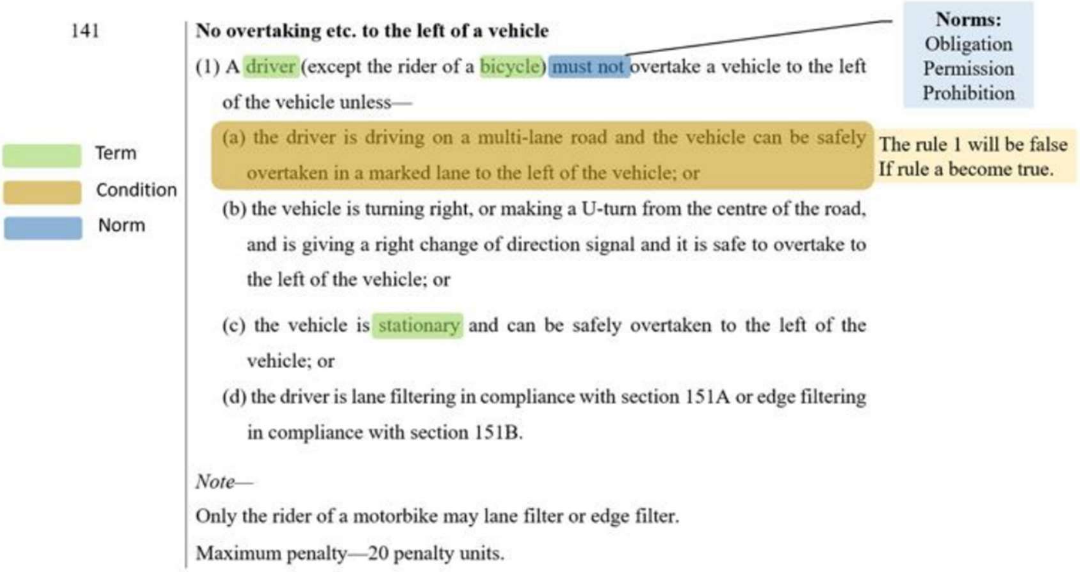
This assessment highlights the significant opportunities for European road operators to leverage digital technologies across various categories of traffic rules, with particularly high potential in areas critical for safety, efficiency, and the future of automated mobility.

4.1.3 Traffic rule digitisation mechanism

In general, traffic rules are expressed in natural language and are created for human drivers. Traffic rules are often very detailed and complex and, therefore, it is a big challenge to encode them (Bhuiyan et al., 2020). Rule encoding is vital for compliance checking, automated reasoning, and legal validation. However, it is complex due to domain-specific language, sentence length, clause embedding, and structure. Additionally, rules contain numerous provisions and intricate norms, making encoding more challenging.

The first part of traffic rule digitisation is to break down the traffic rules from its sentence from into smaller components known as terms, norms, and conditions as discussed by Bhuiyan et al. (2020).

Figure 6 and Figure 7 provide an example of traffic rule broken down into components: terms, norms and conditions.



🟩 Term
🟧 Condition
🟦 Norm

141 **No overtaking etc. to the left of a vehicle**

(1) A driver (except the rider of a bicycle) must not overtake a vehicle to the left of the vehicle unless—

(a) the driver is driving on a multi-lane road and the vehicle can be safely overtaken in a marked lane to the left of the vehicle; or

(b) the vehicle is turning right, or making a U-turn from the centre of the road, and is giving a right change of direction signal and it is safe to overtake to the left of the vehicle; or

(c) the vehicle is stationary and can be safely overtaken to the left of the vehicle; or

(d) the driver is lane filtering in compliance with section 151A or edge filtering in compliance with section 151B.

Note—

Only the rider of a motorbike may lane filter or edge filter.

Maximum penalty—20 penalty units.

Norms:
Obligation
Permission
Prohibition

The rule 1 will be false
If rule a become true.

Figure 6: An example of overtaking traffic rule (Bhuiyan et al., 2020)

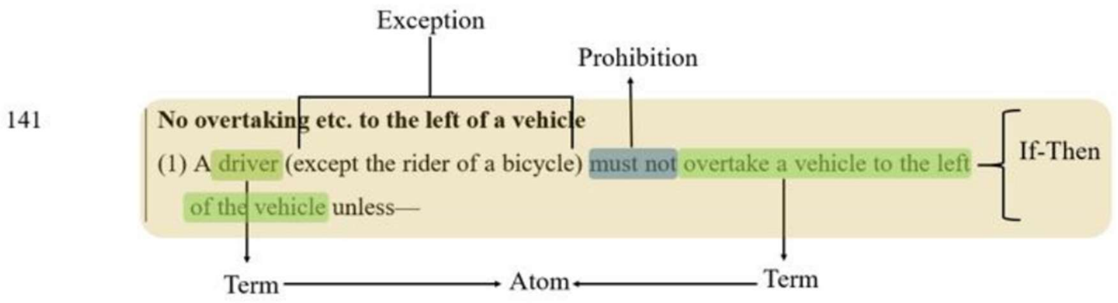


Figure 7: Terms, norms and conditions components in traffic rule (Bhuiyan et al., 2020)

Terms are main actors and subjects in the traffic rule. This refers to those variables and constants that refer to subject (s), predicate (p), property (pr), object (o), and qualifier (q) in the rule sentence. In logic, subjects are variables or constants in rule sentences that refer consistently to certain entities. Predicates describe the properties or actions associated with these entities. Properties indicate the relations between subjects and predicates. Objects refer to the properties of the entities being discussed. Qualifiers are variables that enhance or limit the scope of the entities.

Norms set baseline conditions and are open to exceptions, which are also norms. Norms guide behaviour through permissions, obligations, and prohibitions.

Norms specify conditions in rules to perform actions. Each norm has one or more rules, either constitutive or prescriptive. Constitutive rules define terms in legal documents, while prescriptive rules encode obligation, permission, and prohibition, including the conditions under which they apply. An obligation requires action to avoid a violation, while prohibition restricts an action to prevent a violation. An example of constitutive and prescriptive norms is shown in Figure 8.

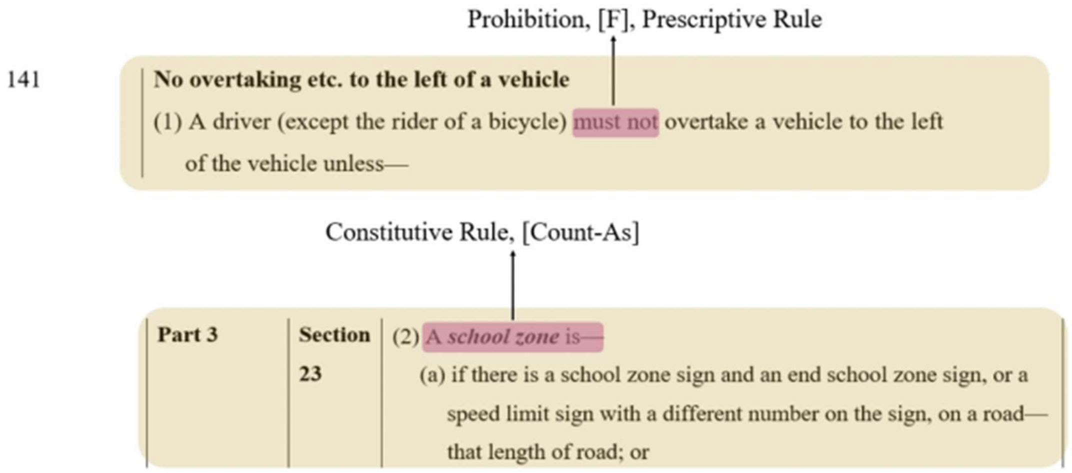


Figure 8: An example of Norms in traffic rule (Bhuiyan et al., 2020)

Conditions provide circumstances which may impact the applicability of the rules. From a legal perspective, rules use conditions on some actions to achieve particular behaviours. The condition is usually a if-then structure.

The broken down traffic rule is then converted into semantical logical format. There has been a couple of different mechanisms proposed to digitise the traffic rules and regulations. Bhuiyan et al. (2020) developed a workflow of traffic rule encoding as shown in Figure 9.

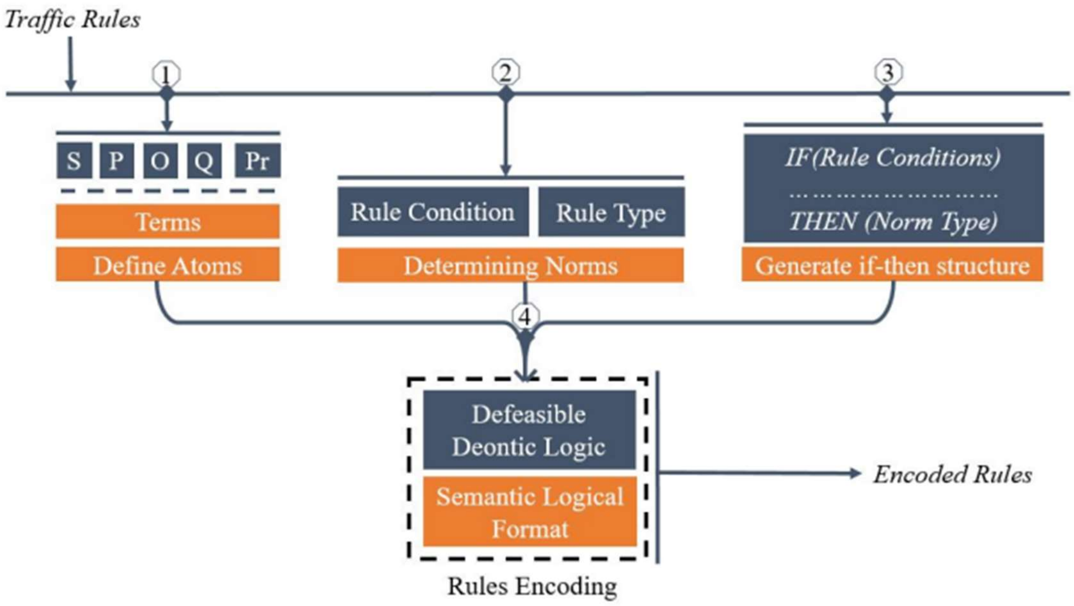


Figure 9: Workflow of traffic rule encoding (Bhuiyan et al., 2020)

The various components of traffic rule namely terms, norms and conditions are combined to create a semantic logical format or a traffic rule in digital format.

Another mechanism proposed by Wan et al. (2023) showcases a five step process for digitising a traffic rule as shown in *Figure 10*.

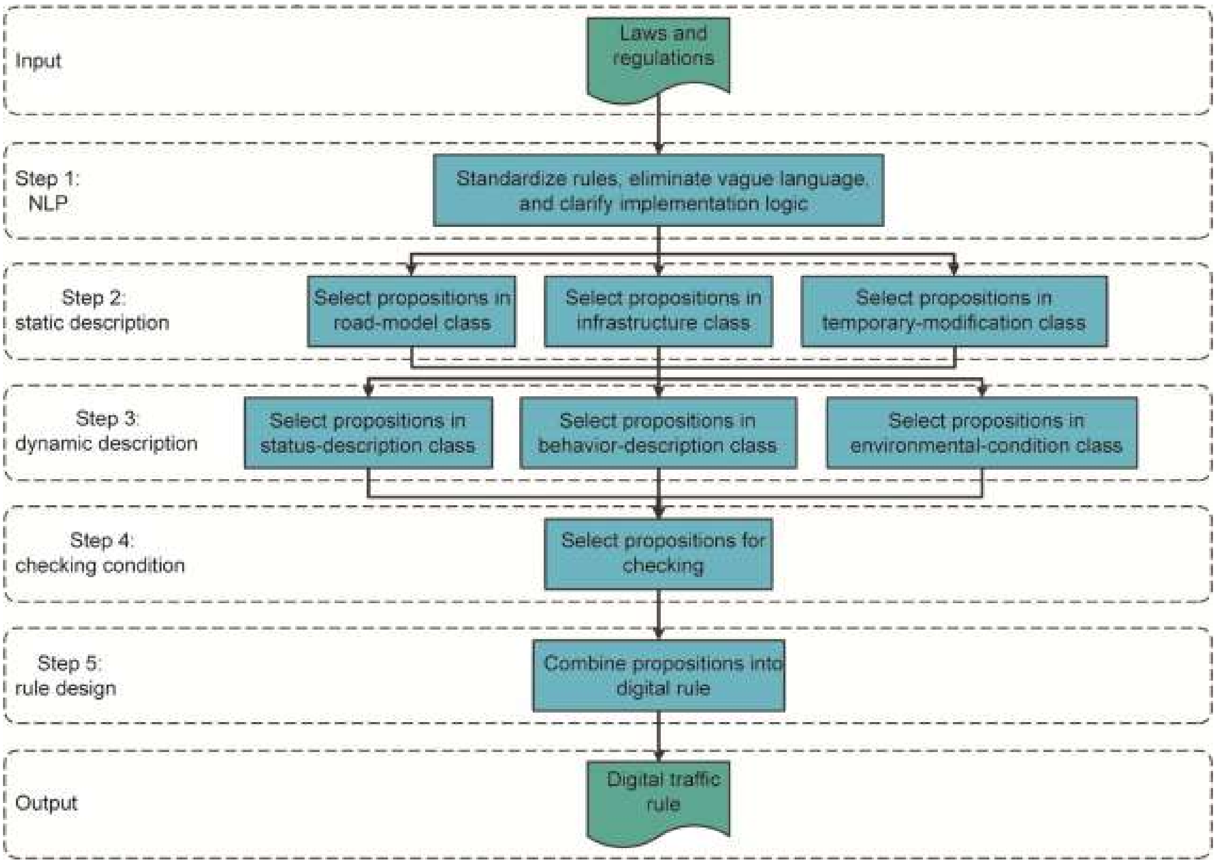


Figure 10: Traffic rule digitisation flowchart by Wan et al. (2023)

The process of digitizing traffic rules involves five streamlined steps (Wan et al., 2023):

1. **Normalization (step 1)**: Convert the traffic rule from natural language to a computer-readable format.
2. **Scenario Description (step 2 and 3)**: Describe the traffic scenario using static and dynamic propositions to capture the environment and behaviors of traffic participants.
3. **Judgment Conditions (step 4)**: Outline the conditions needed for the traffic rules using propositions.
4. **Digitization (step 5)**: Create digital traffic rules in the form of formulas or program code.

These steps ensure that traffic rules are accurately translated into a format that computers can easily process and apply.

A mechanism has developed by Huffman (2023) to adapt the California vehicle code into a Machine-Readable Database to improve legal compliance in automated driving systems. In this mechanism a robust data extraction process was developed to break down a single text code into its database parts. The parts include features like metadata, applicability, rule vagueness, key characteristics, exceptions, and legal outputs. The flowchart for this mechanism is shown below in Figure 11.

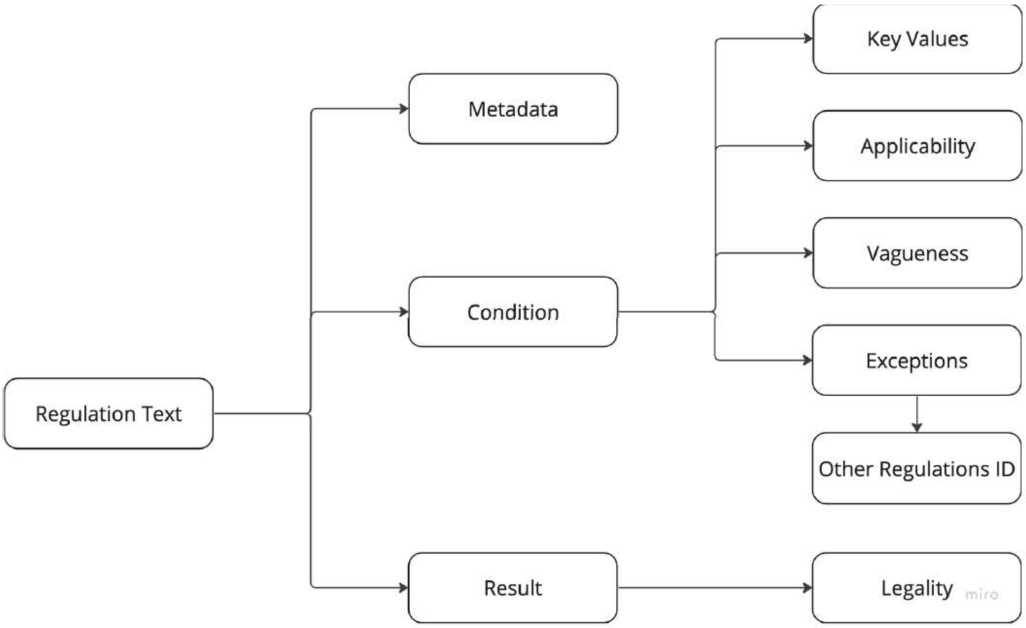


Figure 11: Code extraction flowchart (Matthew Greggory Huffman, 2023)

These mechanisms provide a basic overview of process of converting traffic rules in sentence form to a digital machine readable form. List of several other research which discusses the mechanism of traffic rule digitisation is shown in Table 6.

Table 6: List of references indicating mechanism of traffic rule digitisation

Topic	Discussed rule(s)	Developed mechanism
LLM based framework for Metric Temporal Logic Formalization of Traffic Rules (Manas et al., 2024)	German traffic rulebook *Straßenverkehrsordnung* (StVO)1	Employs large language models (LLMs) to automatically translate traffic rules (TR) into metric temporal logic (MTL)
Extending Urban Multi-	Road junction rules of UK	Capturing the spatio-temporal

Lane Spatial Logic to Formalise Road Junction Rules (Schwammberger & Alves, 2021)	Highway Code	aspects of rules
Ensuring AVs abide traffic rules (Alves & Schwammberger, 2022)	Rule 170 and 171 of UK Highway traffic Code	Formalization and verification of digital version of traffic regulations by developing techniques for finding and resolving conflicts between traffic rules and introducing verifiable, traffic rule-following, autonomous agents.
Traffic Rules for Accountability of Autonomous Vehicles (Rizaldi and Althoff, 2015)	Vienna Convention on Road Traffic for highway scenarios	Formalizing a subset of traffic rules for legal liability of two AVs collision.
Vagueness of rules (Rizald et al., 2017)	German overtaking traffic rules from German traffic rulebook *Straßenverkehrsordnung* (StVO)	Formalising and Monitoring Traffic Rules for Autonomous Vehicles

4.1.4 Traffic rule digitisation initiatives

Europe is witnessing a growing number of initiatives aimed at digitising traffic rules and regulations at various levels, from EU-wide directives to national and local projects.

At the European Union level, the **ITS Directive (2010/40/EU)**[6] **and its revision** are key drivers. The revised directive aims to make high-quality and timely data available for services like multimodal journey planners and navigation systems, extending its scope to include emerging services and setting targets for the digitisation of crucial information such as speed limits and roadworks[7]. The original directive laid the groundwork for data accessibility through National Access Points[8].

DATEX II is another initiative facilitating European electronic language for exchanging traffic information and data. DATEX II facilitates information exchange from data sources to consumers and enables joint traffic management by authorities. It standardizes data provision across all vehicle types and digitally represents road infrastructure dynamics and incidents. The system covers road usage management, including street conditions, traffic measures, parking, charging, and refueling. Information is distributed in a format-independent manner, minimizing misunderstandings and allowing recipients to choose presentation formats. Figure 12 presents various components of DATEX II which highlights the inclusion of traffic regulations as one of its data subdomain[9].

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[6] https://eur-lex.europa.eu/eli/dir/2010/40/oj/eng

[7] https://transport.ec.europa.eu/news-events/news/sustainable-transport-rules-boost-intelligent-transport-systems-safer-and-more-efficient-transport-2023-06-09_en

[8] https://horizoneuropencpportal.eu/sites/default/files/2023-09/eueip-digitalisation-2021.pdf

[9] https://datex2.eu/specifications/

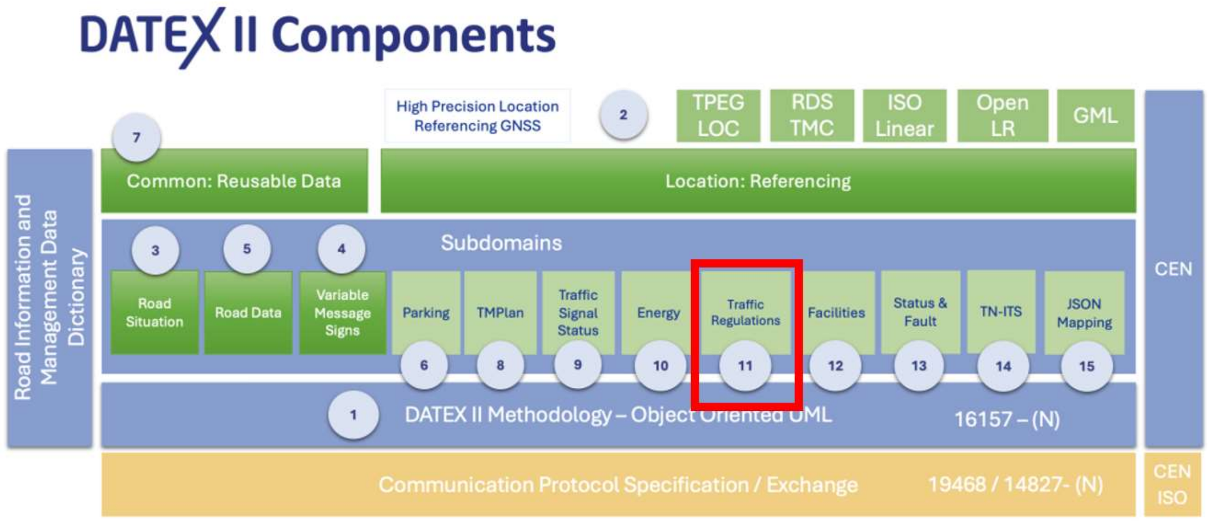

Figure 12: DATEX II components (https://datex2.eu/specifications/)

Several national and regional initiatives are also underway. The **UK's Digital Traffic Regulation Orders (D-TROs)** initiative mandates the digitisation of all traditional TROs and TTROs by summer 2025 under the Automated Vehicles Act 2024[10]. This initiative promises benefits such as streamlined processes, faster decision-making, and enhanced public communication. Austria's **ESTRAL** project focuses on developing practical concepts for the digital regulation of traffic measures to provide context-relevant information and support automated vehicles[11].

Industry initiatives also play a role. **ISO TC204** is developing the **Management of Electronic Transport Regulations (METR)[12]** standard to provide rules of the road in a trustworthy electronic format, crucial for the deployment of autonomous vehicles. The ongoing work within METR standard will lay a firm foundation for digitisation of traffic rules and regulations. The METR is discussed in detail in chapter 4.2.

The EU also promotes Connected, Cooperative and Automated Mobility (CCAM) through the Horizon Europe Partnership, driving innovation in automated mobility technologies[13]. The development of a **European Mobility Data Space (EMDS)** aims to facilitate data access and sharing to strengthen Europe's position in AI-driven mobility solutions[13]. The **European Electronic Toll Service (EETS)** represents another EU-level initiative in digitalising road-related processes[14].

Other initiatives and projects relevant to traffic rule and regulation digitization are as follows:

RTTI regulation and ITS directive obligations

The European Commission published Delegated Regulation (EU) 2022/670 regarding EU-

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[10] https://ttf.uk.net/digital-traffic-regulation-orders-d-tro/
[11] https://www.logistikum.at/uploads/images/PDF/Projektinfoblatt_ESTRAL_E.pdf
[12] https://iso-tc204.github.io/iso24315/
[13] https://digital-strategy.ec.europa.eu/en/policies/technologies-digitalisation-transport
[14] https://interoperable-europe.ec.europa.eu/collection/rolling-plan-ict-standardisation/european-electronic-toll-service-eets

wide real-time traffic information services (known as RTTI regulation), under the Directive amending Directive 2010/40/EU on Intelligent Transport Systems in road transport and interfaces with other modes of transport (known as ITS directive). RTTI regulation indicated static and dynamic traffic regulations as a “crucial” type of data (Laine et al., 2024). This includes critical traffic rules and regulations such as traffic signs, speed limits, access restrictions, overtaking rules, weight/width/height restrictions, HGV rules etc.

Lex2vehicle project analyzes how traffic regulations should be designed so that automated vehicles can also easily follow them in the future. There is a clear strategic objective behind all activities in lex2vehicle: Every road user and every automated driving system must be as clear as possible about what they are allowed to do and what they are not allowed to do at every point in the road network, at all times and in every situation. The aim is to create a *behavioral framework* that is as clear and common as possible. The lex2vehicle approach supplements this existing flow of information with a fully digital component: laws and regulations are then also published as structured data sets. These data sets are reliably transferred to the vehicle and received there in a *legally secure manner*.

Nordicway 3 is a C-ITS pilot project involving Finland, Sweden, Norway, and Denmark. The project facilitates communication of safety hazards and other road information among vehicles, infrastructure, and network operators in the Nordic countries[15]. NordicWay 3 have conducted research on provision of digital traffic rules via DATEX/METR (Magnus Gustin, 2024).

BaustellenInfo digital is an initiative by MWVLW Rheinland-Pfalz to improve roadworks coordination and provide timely information to road users. It digitises traffic regulations related to roadworks, creating a database for better planning and interaction between administrations before regulations take effect (Kleine & Ministerium für Wirtschaft, Verkehr, Landwirtschaft und Weinbau Rheinland-Pfalz, 2018).

4.2 Management of Electronic Transport Regulations (METR)

METR, stands for Management of Electronic Transport Regulations, is an ongoing standardisation initiative within ISO TC/204 WG19 for provision of traffic rules and regulations that ***machines*** can ***understand*** and ***trust***.

METR will specify machine-readable formats for transportation rules, mechanisms for rule exchange, and authentication requirements. These include updates, maintenance, and storage. Rules-of-the-road pertain to surface transportation regulations, encompassing context such as time, location, and applicability. One of the key goals of METR is to facilitate the integration of AV technology with the users and operators of the transportation system (“METR - Overview,” n.d.). However, it is to be noted that METR is not just for AVs but meant for all transport user systems. This includes: vehicle systems (e.g., automated driving systems and driver support systems), sidewalk delivery robots, and other devices such as smartphones used by pedestrians and perhaps units on-board micromobility devices (e.g., e-scooter interfaces) (ISO/TC 204/WG 19 et al., 2022).

4.2.1 Traffic Regulation Order (TRO) and current practices

Traffic regulation orders (TROs) are legal order prepared and announced by a local authority or road authority to regulate traffic on roads in the jurisdiction of the authority. Traffic regulation orders (TRO’s) essentially create local laws which are put in place through a statutory process

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[15] https://www.nordicway.net/

in line with The Road Traffic Regulation Act 1984 (Jasonwheelhouse, 2024).

For example a road authority's decision to reduce speed limit in built up area or regulations related to parking, road works, height restrictions, weight limits, banned turns, one way street, experimental layouts etc.[16] The number of traffic regulations implemented over time could be vast. For example, Swedish traffic regulations collection has about 240,000 TROs (Gustin et al., 2023).

Current Traffic Regulation Orders (TROs) are published as paper documents by authorities or regulators following consultation and approval processes. These documents are primarily text-based legal papers. In Sweden, it is mandatory to deliver PDF files for TROs (Gustin et al., 2023). Many authorities also maintain digital versions of TROs, such as GIS maps, and design their TROs digitally, but still produce a legal, paper-based final output. Various digital formats of TRO are presently used by different authorities, with multiple software services available from various suppliers. The UK Department for Transport (DfT) mandates that all new TROs must be produced and shared in the correct digital format by summer 2025[16].

4.2.2 Scope of METR

METR as a concept pertains to the entire life cycle of a traffic regulation, starting immediately after it is codified. This includes the complete distribution chain of the regulation, from its creation to its dissemination and sharing with end user devices ("METR - Overview," n.d.).

METR will encompass pre-announced (static) rules that can be accessed ahead of both the location and time of need, as well as emergent rules (dynamic) that account for recent changes just before a vehicle reaches the affected location ("METR - Overview," n.d.).

Within its scope, METR will support both static rules, which can typically be accessed well in advance of the location, and dynamic rules, which field personnel or equipment might change an instant before reaching a particular location. METR aims to cover all transport rules, including dynamic changes like temporary lane closures and signal timing. Both cloud-based and local broadcast methods will be needed to deliver reliable information even during communication outages.

The METR is not intended to be just used by ADS but it is meant for all road users. METR should be able to support virtually any rule that needs to be conveyed to virtually any transport user. For example, the Figure 13 depicts rules for freight vehicles, ride sharing, kerbside usage, micromobility operations, vulnerable road users (VRUs), public transport usage, lane usage, and road works[17].

Presentation on METR overview[18] defines the scope of METR as

> *"METR provides a means for ITS user systems to obtain machine-interpretable, publicly available, transport related, authoritative information for the use of surface transport facilities to better provide safe, efficient, sustainable, comfortable and equitable transport services"*

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[16] https://www.britishparking.co.uk/write/Documents/TIR%20Hub/Digital-TRO-Guide-for-decision-makers-on-their-benefits-0424.pdf
[17] https://iso-tc204.github.io/iso24315p1/metr_overview.html
[18] https://iso-tc204.github.io/iso24315/METROverview.pdf

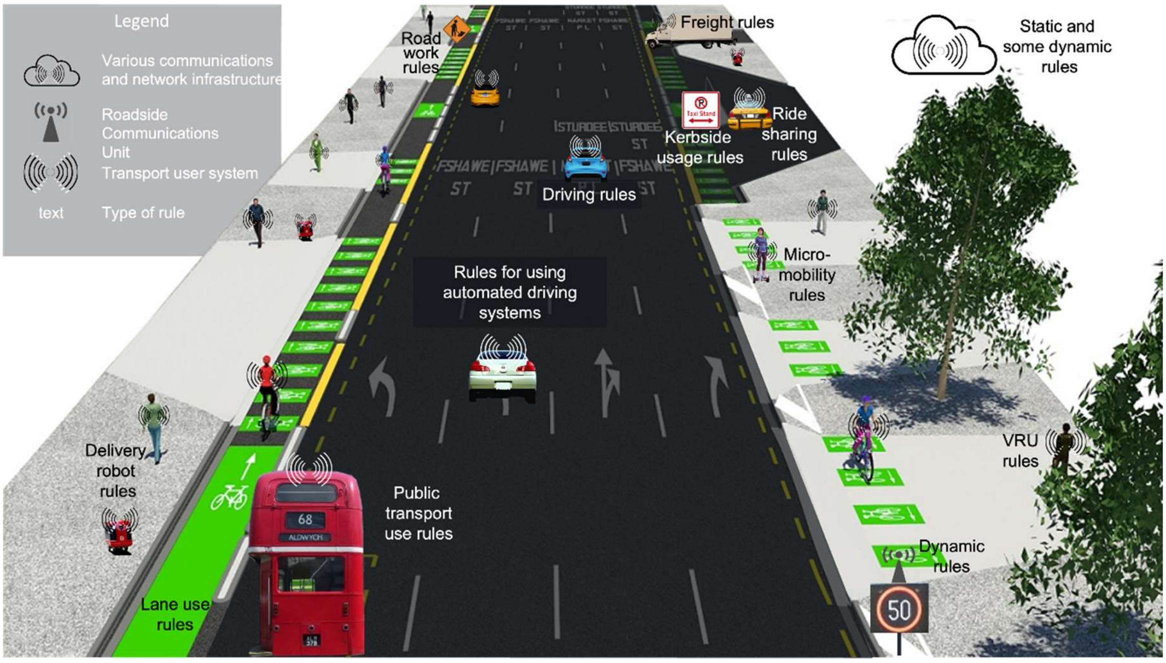

Figure 13: Major type of information covered by METR[19]

Figure 13 provides an overview of the types of information covered by METR[18]. It includes:

- Both dynamic and static authoritative information (i.e., regulations, warnings, and guidance), including speed limits
- Rules for sidewalk delivery drones
- Rules for the use of pedestrian facilities
- Rules for vulnerable road users, including those on pedicycles
- Rules for other micromobility devices, such as segways and e-scooters
- Rules on how vehicles are allowed to interact with the kerbside
- Rules on the operation of ride sharing services
- Rules for freight operations
- Rules for the operation of vehicles within work zones
- Rules for automated vehicles
- Rules for driver assistance systems
- Rules for what vehicles are allowed to use specific lanes
- Rules for the use of public transport
- special rules for freight delivery or heavy vehicles
- road work (e.g., work zone speed limits)
- kerbside usage (e.g., bus stops, taxi stands)
- ride sharing (e.g., allowed forms of ride sharing)
- delivery robot (e.g., maximum speed on sidewalks)

4.2.3 Roles and responsibilities in METR

The METR Vision document (ISO/CEN, 2023) discusses the roles and responsibilities of various actors:

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[19] https://iso-tc204.github.io/iso24315/metr_overview.html

Regulators create TROs affecting traffic movements and roadway uses. Their scope may be federal, provincial, municipal, or campus-based, depending on their governmental position. Multiple regulators may exist for an area due to overlapping scopes. Regulators are primarily involved in non-electronic tasks within the current system. In future systems, one entity might handle multiple roles, such as regulator and translator. Multiple regulators typically have jurisdiction over any given location, requiring compliance with both national and local laws. Additionally, within a single jurisdiction, laws may be enforced by various regulators including motor vehicle, public transport, and police authorities.

Translators convert these regulations into a machine-readable form suitable for distribution, ensuring it can also benefit human users. Multiple translators may be used for various regions and specific travel modes, such as commercial vehicles.

Collectors gathers all required rules from relevant translators and supplies them to the disseminator in a straightforward format.

Disseminators provide access to machine-interpretable regulations using various mechanisms, which may include proprietary methods.

End users include vehicles, travellers, and transport users who need regulation information. Automated vehicles require this data for legal driving, while human-operated vehicles can use it for driver guidance. Pedestrians and other non-vehicle users may similarly acquire this information. Road workers use it for work zone management, and enforcement systems may enhance safety and efficiency.

Figure 1 illustrates the roles and paths regulations follow. Translation, collection, and dissemination can occur nationally, regionally, statewide, or municipally, but METR does not create regulations.

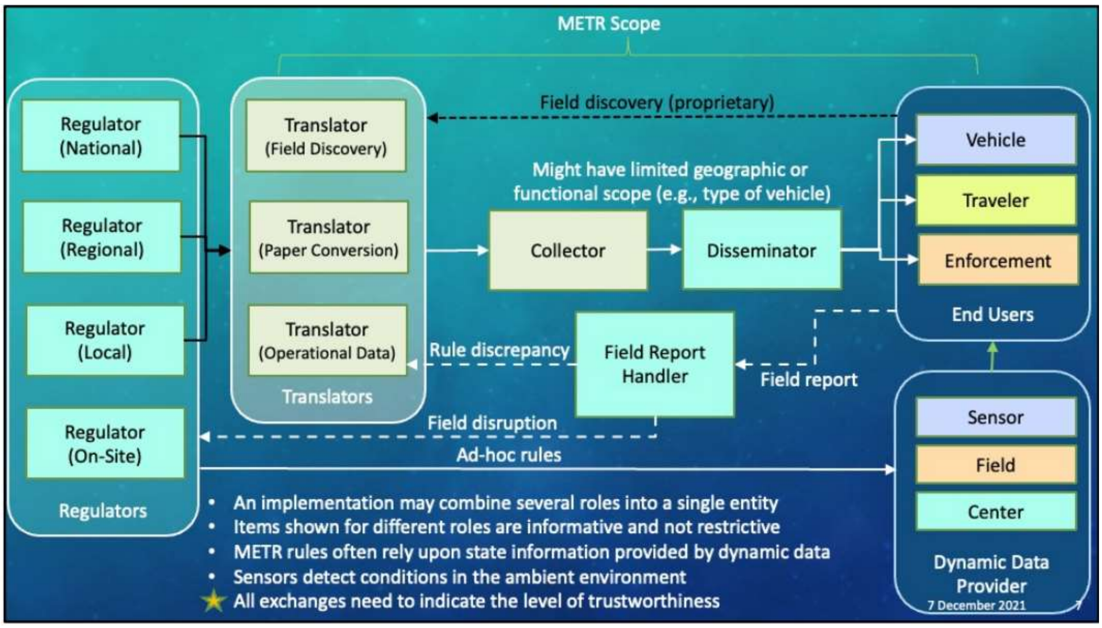

Figure 14: METR roles as discussed in METR deployment I workshop (https://iso-tc204.github.io/iso24315/documents/METR_Wkshp11.pdf)

In the role model shown in Figure 14, the core process for providing static rules involves the following flow: Translators define and digitize the rules, collectors gather them, and disseminators efficiently distribute them to end users.

Above process effectively publicizes known rules using a remote disseminator. However, it cannot cover all situations. Ad hoc rules may be quickly implemented, and local conditions like rain or emergency vehicles can change rule applicability. Therefore, METR also uses dynamic data providers. These include on-board sensors and equipment (e.g., detecting work zones or rain), roadside devices providing C-ITS data (e.g., pedestrian presence, traffic signal status), and central systems providing remote data (e.g., variable speed limits, evacuation notices).

End users may also report field observations. Typically, users provide a field report to a trusted handler, such as an OEM or disseminator, who can relay information while protecting user identity. Handlers manage reports differently; for instance, a discrepancy between an electronic rule and a physical traffic device would be sent to the translator. If a handler notices significant traffic changes or social media reports about an impassable road, they could inform the regulator for official action.

4.2.4 METR process

Figure 15 showcases a schematic representation of process of traffic rule and regulation digitisation within METR as shared during NPRA Webinar (NPRA, 2025). METR focuses on mainly two processes. First, digitalisation of TROs. The traffic authority or regulator issues a TRO which is then translated into digital format by translators as described in section 4.2.3. The TRO is then stored in a digital TRO database which also associated with national road database (NRDB) and location via HD maps. More details about HD maps are covered within this deliverable under Use case 1 (section 5.1). These constitute the static traffic regulations. Second process focus on dynamic traffic regulations. METR also enables provisioning of dynamic traffic regulations which can be issued on by traffic management centre. The collection of static and dynamic traffic regulations forms the METR system.

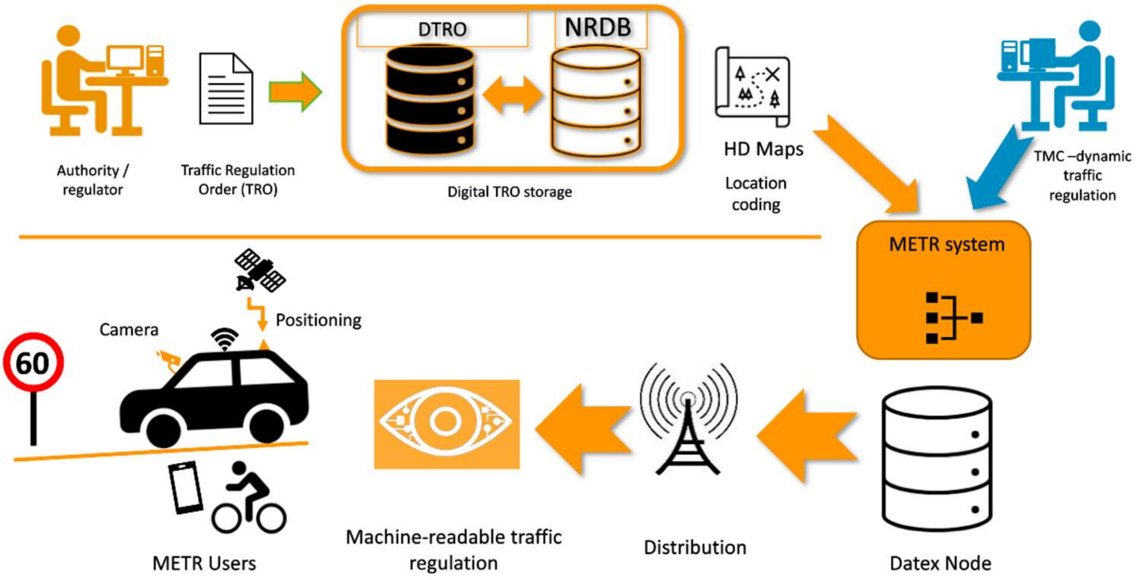

Figure 15: A schematic representation of METR process flow as shared during NPRA webinar on METR (2025)[20]

The traffic regulations within the METR system can be shared using DATEX and distributed to the end users via various communication channels. The end users can utilise their position and physical infrastructure to determine the applicable rules.

Figure 16 showcases another visualisation of METR process. It is important to note that cybersecurity and trust are key components in METR as the impact of shared information have

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[20] https://www.vegvesen.no/fag/trafikk/its-portalen/its-i-statens-vegvesen/metr/

real consequences. The provisioned information can be verified and validated with the help of ETSI based certificates and signatures. The security and trust aspect are covered within the TIARA project.

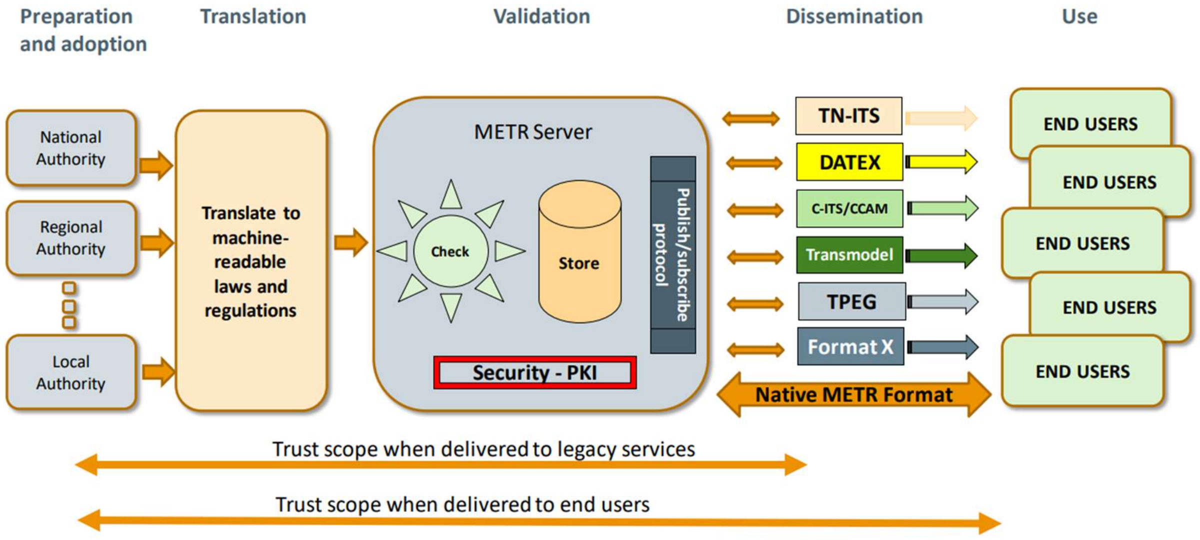

Figure 16: The METR process[21]

Figure 17 highlights the difference in process between static and dynamic traffic regulation digitisation (Magnus Gustin, 2024). The main difference lies in the first step where static TROs are issues by the lawmakers. On the other hand, the dynamic regulations are based on real time situation on road and applicable dynamic measures based on the situation. This real time information can come from *Digital Twin* of the road infrastructure.

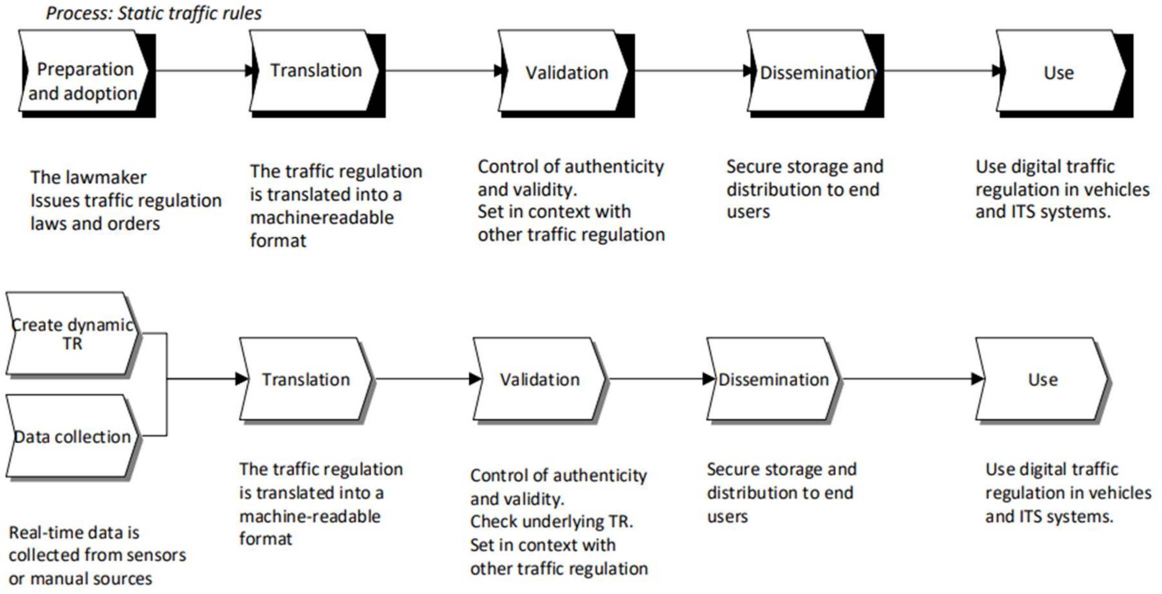

Figure 17: Process of static (top) vs dynamic (bottom) traffic regulations

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[21] https://napcore.eu/wp-content/uploads/2023/12/METR-and-Napcore-r1.pdf

4.2.5 Example: Provisioning of speed limits (ISA information) via METR[21]

A Speed Regulation can be created in a GIS-tool by an authority. A speed zone is designated, and time of validity, exact location, special usage are added. The METR information about speed limits can be shared via DATEX (Figure 18) where a header is included with the following information:

- Information that this is a speed regulation
- Exact geolocation of the speed zone
- Start/stop time of validity
- Other service-specific information

A certificate based on the ETSI format includes METR SSP (Service Specific Permissions) and the identity of the official with regulatory permissions. A signature based on ETSI/P1609.2 SignMessage is applied over the entire set (Header, Regulation, Certificate).

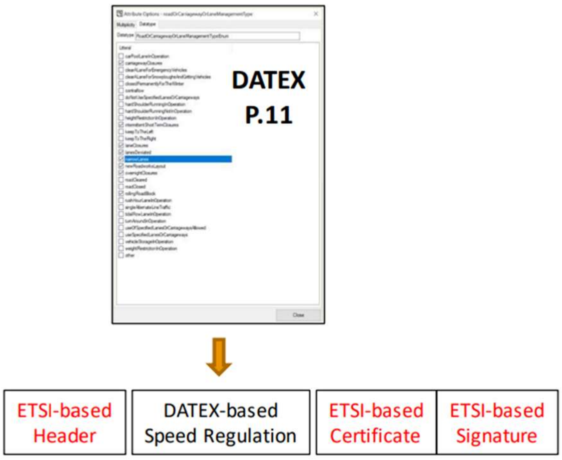


Figure 18: Example of digital speed limit regulation and associated certificates for validation and trust[21]

Figure 19 provides an example of static and dynamic speed limit provisioning via METR.

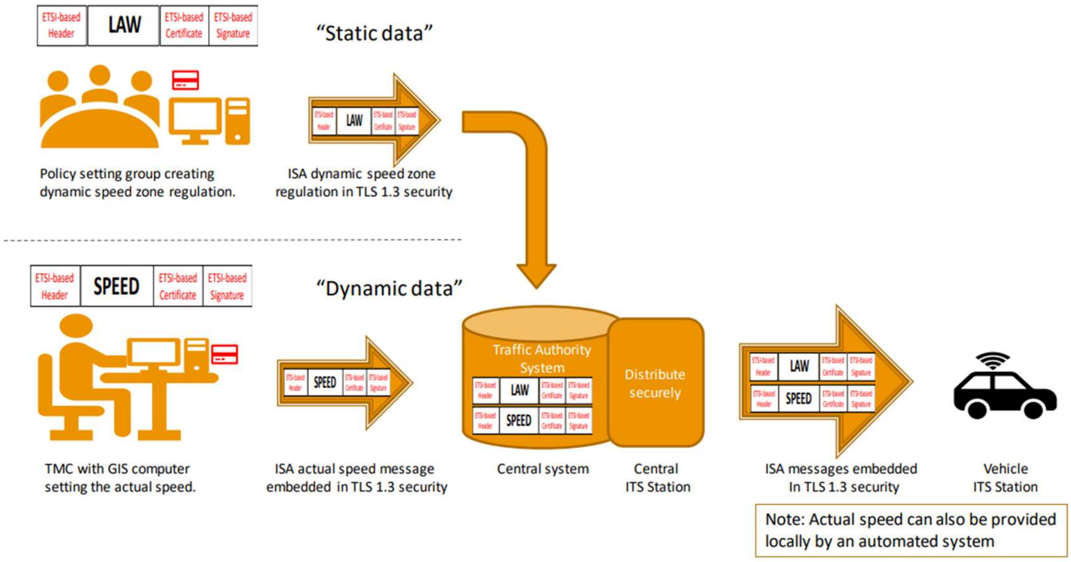


Figure 19: Static and Dynamic speed limits in METR process

4.2.6 METR standardisation status

Figure 20 provides an overview of various European standards within CEN TC278 ITS. The working group WG17: Mobility integration was introduced to connect all other standardization initiatives from WG1 to WG16. METR is also a part of WG17 developments. METR relies on other European standards such as DATEX-II or TN-ITS. For standardization development, the ISO working groups in connection with European working groups.

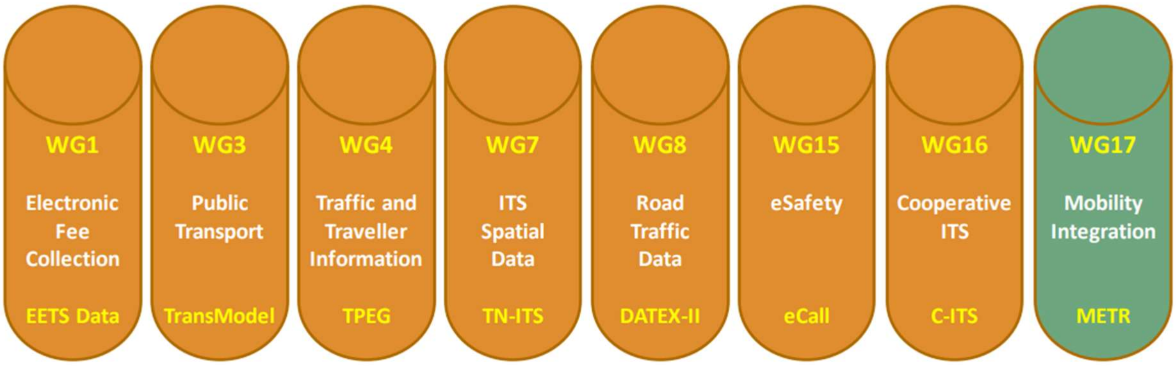
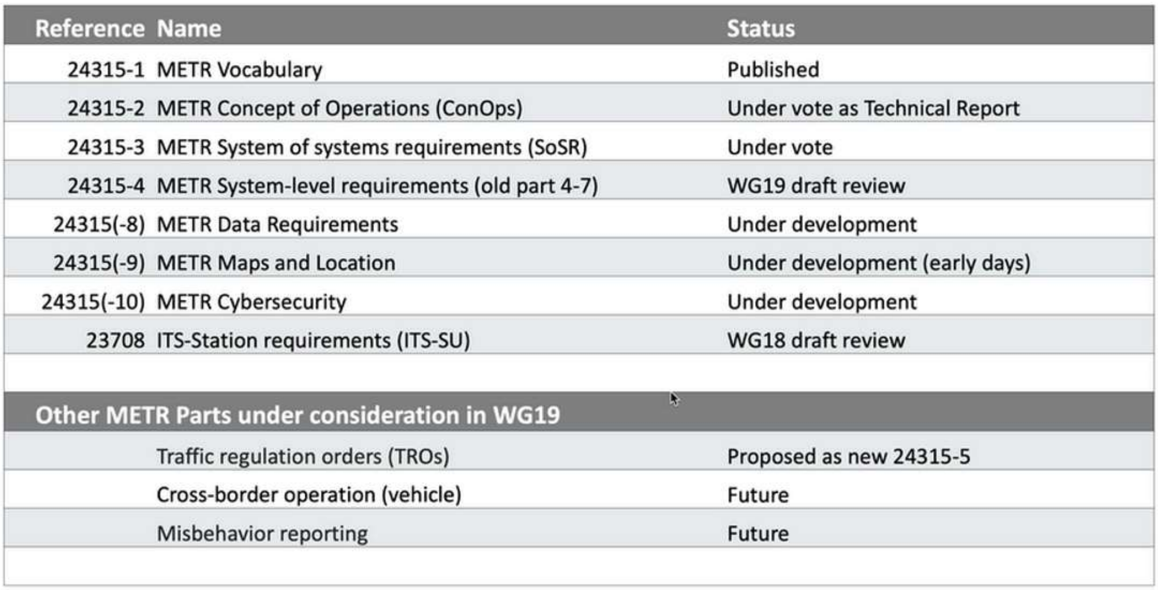


Figure 20: An overview of European standards CEN TC278 ITS[21]

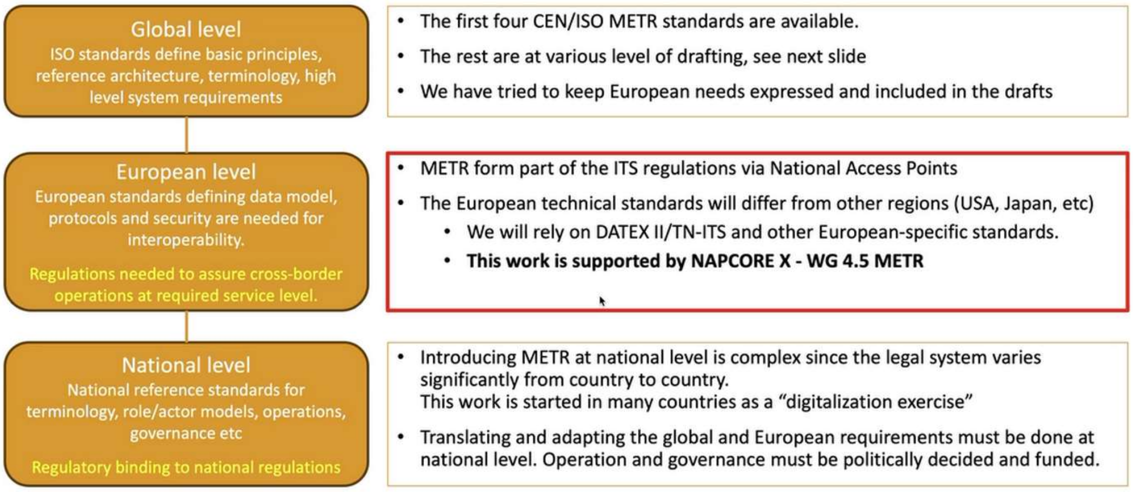
Table 7 provides an overview of various METR ISO standards. The first four CEN/ISO standards are available whereas many standards are in a draft stage. The European METR standardisation suggests it to be a part of ITS regulations via National Access Points (NAP) as shown in Figure 21. Regulations are needed to ensure cross-border operations at required service level.

Table 7: METR ISO standards overview



Reference	Name	Status
24315-1	METR Vocabulary	Published
24315-2	METR Concept of Operations (ConOps)	Under vote as Technical Report
24315-3	METR System of systems requirements (SoSR)	Under vote
24315-4	METR System-level requirements (old part 4-7)	WG19 draft review
24315(-8)	METR Data Requirements	Under development
24315(-9)	METR Maps and Location	Under development (early days)
24315(-10)	METR Cybersecurity	Under development
23708	ITS-Station requirements (ITS-SU)	WG18 draft review
Other METR Parts under consideration in WG19		
	Traffic regulation orders (TROs)	Proposed as new 24315-5
	Cross-border operation (vehicle)	Future
	Misbehavior reporting	Future

Figure 21 presents various levels of ISO standards as also seen in DROIDS deliverable D3.2 (Soni, S., 2024). The focus towards standardisation is more on European level. It is also crucial to adapt the standards for national context to allow region specific regulations and language. The standard development committee expects at least 2 more years of work ahead to finalise the METR standards.



Global level
ISO standards define basic principles, reference architecture, terminology, high level system requirements

- The first four CEN/ISO METR standards are available.
- The rest are at various level of drafting, see next slide
- We have tried to keep European needs expressed and included in the drafts

European level
European standards defining data model, protocols and security are needed for interoperability.
Regulations needed to assure cross-border operations at required service level.

- METR form part of the ITS regulations via National Access Points
- The European technical standards will differ from other regions (USA, Japan, etc)
  - We will rely on DATEX II/TN-ITS and other European-specific standards.
  - **This work is supported by NAPCORE X - WG 4.5 METR**

National level
National reference standards for terminology, role/actor models, operations, governance etc
Regulatory binding to national regulations

- Introducing METR at national level is complex since the legal system varies significantly from country to country.
  This work is started in many countries as a “digitalization exercise”
- Translating and adapting the global and European requirements must be done at national level. Operation and governance must be politically decided and funded.

Figure 21: Split of responsibilities: Global – Regional – National

Several countries are frontrunners in adapting METR to their national standards and digitising traffic rules. Standards Norway has published their first Norwegian METR standard[22]. The **UK's** Digital Traffic Regulation Orders (D-TROs) mandate also is a big step ahead towards achieving METR digitisation goals.

4.3 Priority of rules and regulations for digitisation

In order to gain an understanding of traffic rules and regulations deemed important for digitisation by road operators, we asked workshop attendees and questionnaire respondents which rules or regulations would they like to see digitised and in what priority.

The various priorities indicated by each country is shown in Table 8. It is important to be noted that the priority for information digitalisation differs between countries.

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[22] https://kommentere.standard.no/nb/enquiry/515b3390-7aba-4bcf-9d21-08dce7770a7d?tab=general-information

Table 8: Indicated priorities of traffic rules for digitisation

Country	**Priority 1**	**Priority 2**	**Priority 3**	**Priority 4**	**Priority 5**
Belgium	Safety critical information	Road works/closures	All physical signs next to the road	-	-
Denmark	Safety critical information	Traffic flow management	-	-	-
Finland	Speed Limit	Access restrictions such as UVAR	Other regulatory signs	General traffic rules and regulations	Required behaviour at incident and road works sites (dynamic)
Germany	Legally allowed behaviour under certain conditions (weather, visibility, etc.)	Everything else	-	-	-
Ireland	Speed limit	Road works	Incidents	Events (increased traffic/pedestrians etc.)	-
Norway	TROs	Low Hanging fruits	-	-	-
Romania	Road Markings	Speed limits	Traffic signs (no entry, no stopping, no overtaking)	Height restrictions	Weight restrictions
Switzerland	Speed limits	-	-	-	-
Sweden	Speed limit	Road and lane closure	Forbidden - turn, direction, entrance, etc.	Traffic management measures	-
The Netherlands	Speed limit	Road closure	Incidents	Overtaking ban for trucks	Restrictions for transport of dangerous goods
UK	No-entry, One way route limitations - prohibited movements.	Digital variable message signs - e.g. variable speed limits & lane closures	Fixed Speed Limits	Road classification - vehicle type regulations etc.	Temporary traffic diversion routes

The inputs were consolidated in various priorities to get a high-level overview. Figure 22 provides an overview of various traffic rules and regulations and their priorities for digitisation. The rules which were indicated as high priority by at least 3 stakeholders overall are bold and underlined.

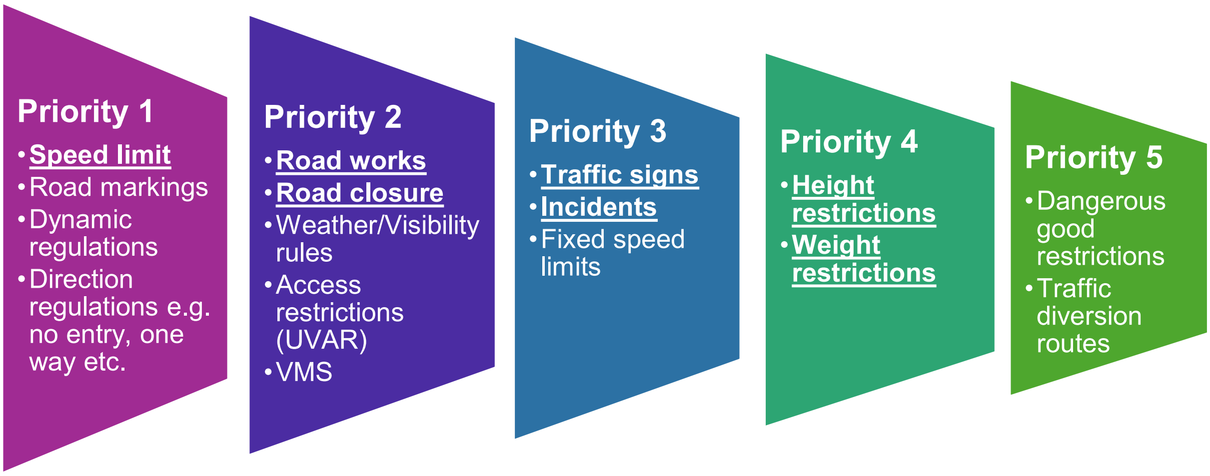

Figure 22: Priorities of various traffic rules and regulations for digitisation as indicated by stakeholders

The opinions about the priority for digitization of traffic rules in view of road operators and other stakeholders varied in a spectrum. Some stakeholders did not specify a certain priority for digitization. Rather, they relied it on the context such as big cities, region, or easiness of digitisation of rules. Some stakeholders specified the digitization of traffic rules in a more generic terms like all formal and informal rules.

From the workshop conversations and analysis, road operators emphasized on prioritising safety critical information in first place. In addition, the information that is required to be digitised under Traffic Regulation Orders (TROs), RTTI/SRTI regulation and ITS obligations were also given priority for digitalisation.

The speed limits were identified as the highest priority for digitization due to their critical role in safety and the mandate of ISA as per Regulation (EU) 2019/2144[23]. The importance of dynamic traffic information, such as variable message sign (VMS) information, was also emphasized. This includes all dynamic information such as dynamic speed limits, dynamic lane closures, traffic information etc. Road markings (such as lane markings, turning arrows, priority symbols, hatchings, bus lanes, etc) were also indicated a high priority rule for digitisation as it provides important information for the safe operation of the vehicle.

Planned or unplanned disruptions such as roadworks and road closures were also considered high priorities for digitisation as these represent safety critical information and sets expectations regarding driving behaviour around disruptions. Weather and visibility rules were also considered as high priority. In addition, access restrictions (UVAR)[24] such as access to emission zones was also seen as a low hanging fruit for digitisation.

Third priority was indicated toward digitisation of traffic signs such as no overtaking, no stopping etc. as play an important role in safe driving. Rules around incidents such as reducing speed limit, priority to emergency vehicles etc. were also considered in third priority.

Fourth priority rules were more towards heavy goods vehicles (HGV) where height and weight restrictions were seen as important rules to be digitised to ensure safety.

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[23] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=PI_COM:Ares(2021)2243084&rid=1

[24] https://transport.ec.europa.eu/transport-themes/urban-transport/urban-vehicle-access-regulations_en

Lastly, restriction on carrying dangerous goods were seen as another important rule for digitisation.

Reason for such prioritisation

The above prioritisation was made in focus to achieve the strategic goals on traffic safety and traffic flow. Road operators also mentioned that their focus currently is currently on implementing the delegated regulations on Safety-Related Traffic Information (SRTI) & Real-Time Traffic Information (RTTI), and SSTP Delegated Regulation as per ITS directive[25]. These rules are relevant for ADS as it can help them determine the legally allowed behaviour inside their ODD.

The digitisation of traffic rules and regulations with initiatives like METR will help in compliance of the new rules by ADS in addition to basic permissible behaviour. This could help in type approval process for ADS must comply and react to any changes in traffic regulations via TROs. This would help in improving the performance of ADS as reliance on sensors might be prone to error in long run.

The responses also emphasized on initially focusing more on digitising rules and regulations that can benefit both human drivers and ADS. An example of such digitisation is speed limits for ISA, which influence both driving behaviour in ADS but also prevents human drivers from accidently speeding. Road operators also suggested mandating traffic rules in ADS with SAE level 2 and more.

Road operators see benefits of traffic rules digitisation in terms of improved safety, better traffic management and better functioning by ADS.

4.4 Roles of stakeholders in traffic rule digitisation

Digitisation of traffic rules and regulations is a complicated process which involves multiple stakeholders. A role analysis was carried out during the workshop and advisory group meetings to discuss the role of various stakeholders in the ecosystem focussed more towards the role of road operators. Table 9 presents the outcome of role analysis carried out.

Table 9: Role table showcasing the roles of various stakeholders in digitisation of traffic rules and regulation

Stakeholder	Regulation	Standardisation	Development/ digitalisation	Operation (Quality & service assurance / Data delivery)	Maintenance (updating rules)	Compliance	Legal liability
Transport authority (ministry, agency)	A	P	A		A	P	
Communication authority		A	A	A	A	A	
Land use authority (e.g. city, region)		P	A		A		
Law enforcement agencies	A	P	A			A	A

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[25] https://eur-lex.europa.eu/eli/dir/2023/2661/oj/eng

Rescue service provider				A			
Road operators	**A**	**A**	**A**	**A**	**A**		
Traffic manager				A	A	P	
Road infrastructure planning contractor			P				
Road infrastructure building contractor			P				
Road works or maintenance contractor					P		
Traffic information service provider		P	A	A	P		
Meteorological service provider		P	A	A			
Communication service provider		P	A	A	P		
Digital map provider		A	A	A	A		
Vehicle fleet operator						A	A
Vehicle manufacturer		A	P			P	
ADS provider		A				A	A
Research / academic institutes		A					
Vehicle owner/ driver/ occupant						A	A
Local/regional road operators		P	A	A	P		
Private road operators			P	A	P		

*Where **A** refers to active (actually carrying out the task or commissioning it) and **P** refers to a more passive role.*

Various stakeholders plays as role in issuing **regulations**. An indication from transport authority envision their active role in being the regulator of digital traffic rules and regulations. Road operators and law enforcement agencies can also pass traffic regulation orders and thus plays an active role in regulations.

In terms of **standardisation**, many stakeholders play an active as well as passive role in defining the standards. Road operators for example plays an important active role in adapting the standards to their national and regional context. Communication authority also defines standards on how the rules and regulations can be transmitted to end users safely and securely. Research institutions and consultancies contribute to development of specifications, procedures and standards and supporting research and advice. Active involvement of ADS providers, digital map providers and vehicle manufacturers would ensure that standards are interoperable and also implemented across their systems. Various other stakeholders play an passive role in standards development such as transport authority could ensure the standards being developed are in accordance to regulations. Also, cities, local road operators and law enforcement agencies could provide their inputs to allow standards to accommodate their interests. Also, service providers could provide their inputs to ensure standards take into account use of their information specifically from the perspective of dynamic regulations.

Many actors would be playing an active role in **digitisation and development** of digital traffic regulations. Authorities issuing TROs such as transport authority, road operators, land use authority, law enforcement agency etc. would be active in making sure that TRO is available in digital format. The planning and building contractors will play a passive role in provisioning planning information to authorities who can ensure it in digitalised TRO. For example, contractors can inform authorities about any expected delay in road works. Digital map providers can also play an active role in making sure the information available via them contains up to date information for end users. Service providers here play an active role in making sure that digital information provided by them is in correct specifications required.

For the **operation** phase, it is important to validate the digital traffic rules and regulation being shared to the end users and ensure its quality. Many stakeholders would play an active role in data provisioning. Road operators, service and map providers, communication authority, traffic managers, and rescue services providers, all actively ensure that information shared is up-to-date, high quality and validated. The communication authority can also validate if the information is delivered to the end users.

With change in regulations or conditions, the traffic rules need to be updated. Many stakeholders play an active role in the **maintenance** of the traffic rules and regulations. Stakeholders involved in updating rules such as transport authority, road operators, traffic managers, land use authority etc. plays an active role in maintenance. Also, digital map providers need to actively ensure that information shared via digital maps are also up to date. Service providers have a passive role where they make sure that they provide up to date information for integration within systems.

In terms of **compliance** to traffic rules, law enforcement agencies would play an active role. They could be actively supported by communication authority to identify non-compliance cases. Furthermore, vehicle fleet operator, ADS providers and Vehicle owner/ driver/ occupant need to ensure that they actively comply with all traffic rules and regulations. Transport authorities, traffic managers, and vehicle manufacturers could on the other hand passively ensure compliance by spreading awareness.

In terms of **legal liability**, law enforcement agencies play an active role. Furthermore, vehicle fleet operator, ADS providers and Vehicle owner/ driver/ occupant are legally liable in case traffic rules are exploited.

The Table 9 gives a first indication of expected roles of various stakeholders in digitisation of traffic rules and regulations. As the work on standardisation for digitisation of traffic rules and regulations is ongoing, the roles are expected to shift and change in near future.

4.5 Benefits of traffic rules digitisation

Digitisation offers numerous advantages for road operators, impacting various aspects of their responsibilities and the overall performance of their networks. The key benefits due to traffic rule digitisation are:

- **Interoperability** and cooperation between countries will improve due to traffic rule standardisation as it will enable awareness of traffic rules by drivers or ADS[21].

- Establishing **consistent and legally accurate regulatory data**[16], such as maintaining a unified speed limit database rather than relying on cameras, implementing a comprehensive set of height/weight limits and prohibited turns for navigation systems, facilitating faster updates of navigation devices following road closures to assist deliveries and reduce congestion, improving planning for utilities to coordinate works and utilizing TRO data linked to street works.

- **Facilitation of Connected and Autonomous Vehicles (CAVs)** is a major benefit of traffic rule digitisation (ISO/CEN, 2023). Digital traffic rules offer real-time information for self-driving vehicles, ensuring safe operation. An AV that follows digitized rules will likely be a more predictable road user for other drivers, especially if those rules are explicitly disclosed. Digitized rules might allow for different cultures and localities to specify behaviour for AVs, which could promote integration into the local driving culture. Additionally, the creation of a single source of truth for what is considered good driving would allow the synchronization of behaviour across AV developers and could potentially contribute towards a safer road transportation system. Furthermore, digitized rules reduce the risk of regulatory ambiguity. Digitized rules also constitute an additional layer of information, thus creating redundancies between different sources of information for AVs.

- **Improved traffic management (ISO/CEN, 2023)**: When users can receive machine-interpretable regulations, new opportunities arise. Road operators can dynamically implement zone operations, and digitized regulations may enable more automated enforcement techniques. Limited access resources like sidewalks, loading zones, parking spaces, and crosswalks can be dynamically controlled. Digital traffic regulations could enable:
    - Legally enforceable restriction zones, depending on performance and connectivity regulations.
    - Automated enforcement technologies leveraging METR data for consistent enforcement.

- **Improved Efficiency**[16]: Digital traffic regulation management streamlines processes, reduces administrative burdens, and minimises errors compared to paper-based methods.

- **Enhanced Public Information and Transparency**[16]: Authorities can share real-time updates on road changes directly with the public through digital channels, making traffic management more accessible and transparent.

- **Enhanced Safety** is another significant advantage. Digital technologies facilitate more efficient monitoring and enforcement of traffic regulations. With more accurate information such as speed limits or road works, road users can make more informed driving decisions.

- **Advanced services -** Digitizing traffic rules open opportunities for new services in the long term, such as information that vehicles have been parked incorrectly, warnings before the time for a parking ban or fee obligation comes into effect, etc. It also opens the possibility of more dynamic traffic regulation and advanced services for road users in the long term.

4.6 Challenges in traffic rules digitisation

Digitization of traffic rules and regulations is not without its challenges and requires careful consideration of several key factors.

Data Security and Privacy are of paramount concerns. The increasing connectivity of vehicles and infrastructure leads to the collection of vast amounts of data, raising significant data protection issues[13]. The growing reliance on digital infrastructures also increases the importance of cybersecurity[13]. The EU's NIS Directive and NIS 2 Directive aim to address network and information system security across critical infrastructure[26].

Data Standardization and Interoperability: Varying digital maturity among authorities (Jenny Lundahl et al., 2023) and a lack of common standards result in diverse formats and interpretations of traffic regulations. This hinders seamless data exchange and interoperability between different digital systems and across national borders, crucial for effective traffic management[27]. The need for standardized data formats, as highlighted by the UK's D-TRO[10] initiative, is important.

The existing **Legal and Regulatory Frameworks** may need to be updated or adapted to fully accommodate the implications of digitized traffic rules, digital enforcement, and the operation of autonomous vehicles [1]. Issues such as liability in the context of autonomous driving and the legal validity of digitally issued traffic regulations need careful consideration. The EU AI Act and its tiered approach to regulation will also impact the development and deployment of AI in traffic management [23]. European road operators need to actively engage with policymakers to ensure that the legal and regulatory landscape evolves to support innovation while addressing crucial ethical and legal questions.

Decentralised data: A significant hurdle is the lack of comprehensive and reliable data on traffic rules across entire road networks. This stems from decentralized decision-making by numerous municipalities and government agencies with non-standardized processes. For example, in Sweden, with its 290 municipalities decide about traffic rules. Some use digital tools to create data on traffic rules, others do not. Moreover, municipalities and administrative authorities may decide on a number of traffic rules that supplement or replace the general traffic rules, for example speed limits, prohibition of traffic, duty to stop and give way, lanes for regular traffic, restrictions on vehicle weight/length/width, environmental zone, parking, etc. In Sweden, there are over 300 government agencies and municipalities that decide on traffic regulations locally, regarding a certain stretch of road or area, and their processes for this are not standardized. This issue also exists for example in Finland. While rules for roads and traffic are set by Finnish national authority, there is not a centralized database TRO (Jenny Lundahl et al., 2023).

Adapting Existing Frameworks: Current legal and regulatory frameworks may not adequately address the complexities of digitized traffic rules, digital enforcement, and autonomous vehicles (AVs). Issues like liability in AV accidents and the legal validity of digital traffic regulations require careful consideration. The EU AI Act and its tiered regulatory approach will also significantly impact this area.

Data Quality and Interpretation: Even when data exists, it often suffers from shortcomings in content and quality, making it unreliable for digitization. Furthermore, "translation" of abstract traffic rules into machine-readable data by NRAs, based on interpretations, can introduce inaccuracies. Among countries, there is also a large degree of freedom in how traffic regulations written, which means there is a great variation in the design of traffic regulations at local level. Also, in terms of geography of applied rules there are variance. For example, in some countries there are regionally restricting traffic rules in urban areas like low emission zones, road tolls and air quality emergency (Jenny Lundahl et al., 2023).

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[26] https://digital-strategy.ec.europa.eu/en/policies/nis2-directive
[27] https://horizoneuropencpportal.eu/sites/default/files/2023-09/eueip-digitalisation-2021.pdf

Data Ownership and Liability: The involvement of diverse stakeholders, including GPS providers and mapping companies, raises legal concerns regarding data accuracy and liability. Errors in digital mapping or sensor readings can lead to accidents, prompting questions about who bears responsibility.

Stakeholder Collaboration: Effective coordination between road authorities, technology providers, vehicle manufacturers, type approval authorities and other stakeholders is essential but often difficult to achieve.

Political Will and Resource Allocation: In some regions, like Denmark, a lack of political focus on the digitization of traffic rules results in limited resources and funding. The only focus at the time being is implementing the requirements in the Delegated Acts under the ITS Directive.

AV Driver Education: Drivers often lack sufficient understanding of AV limitations, particularly in adverse weather conditions. Officials also require more education on AV technologies and terminology (Are You Preparing Now for the Roads of the Future, 2020).

Varied Legal Systems: Differences in national legal systems, as seen in the comparison of Germany, Austria, and Switzerland, create variations in traffic law implementation. This complicates the harmonization of digital traffic rules across borders.

Traffic Rule Exceptions: Emergency situations and exceptions to traffic rules, which are critical in human driving, are not adequately addressed in current AV research and development (Kumar Manas & Adrian Paschke, 2023).

Cultural and Regional Norms: Variations in cultural and regional interpretations of traffic rules pose challenges in ensuring consistent application. A lack of a clear process for resolving conflicting interpretations further complicates matters (Bin-Nun et al., 2022).

Road operators may also face challenges related to **Legacy Systems and Infrastructure** that are not easily integrated with new digital solutions. **Funding and Investment** are significant considerations, as implementing sophisticated digital traffic management systems requires substantial financial resources. Ensuring **Public Acceptance and Adoption** of digital traffic rules and enforcement mechanisms is crucial for their success. Finally, road operators must consider the **Digital Divide** and ensure that all road users, regardless of their access to technology or digital literacy, can understand and comply with traffic regulations.

4.7 Recommendations for road operators

The METR working group and Norwegian Public Roads Administration (NPRA) during their webinar hosted on 25th March 2025 highlighted that road operators should try to be involved with the standardisation process as early as possible. The first step towards getting involved with METR development is *to follow the ongoing standardisation process* and understand the standards in detail (for example understand the first three parts of ISO standards for METR). Furthermore, *participating in standardisation efforts* at national and European level would benefit road operators in gaining maturity and knowledge for implementation of METR. Also, the road operators should think from their *local perspective* on what is required for them. Sharing of specific requirements would also help in shaping METR to a wide variety of situations and use cases. The road operators should *share knowledge* among each other and align their interests to ensure interoperability. The NPRA indicated that being frontrunners, they are happy to share their work and support other countries.

In terms of digitisation of traffic rules, the road operators suggested *focusing on simple and* *easy to achieve regulations* first. For example, speed limits which are mandated to be digitised for Trans-European Transport Network (TEN-T) by December 2025 and entire public road network by December 2028[28]. The road information signs for example can be a second priority for digitisation as suggested during workshop.

It is crucial for the road operators to *develop a clear digitalisation strategy* that outlines specific objectives, priorities, and timelines for this transformation, aligning with both national and European Union level initiatives. In addition, road operators road operators must Invest in *robust data infrastructure and capabilities*, focusing on the collection of high-quality data, the establishment of data standards, and the development of robust data management systems. The processes for creating TRO for example could be more uniform with focus towards digitisation.

Also, in addition to updating and maintaining the traffic regulations, road authorities must ensure a high-quality infrastructure for ADS. The road operators could periodically conduct assessment of infrastructure for functioning of ADAS systems like ISA and identify issues with digital information as well as physical elements. For example, for the sign to be effective, it has to be clearly visible and easily understood by the vehicle's machine vision system. This means that signs must deliver high luminance and retro-reflectivity in all conditions and be durable to withstand challenging environments (Are You Preparing Now for the Roads of the Future?, 2020). Collaboration and partnerships with technology providers, research institutions, and other stakeholders will be key to leveraging expertise and accelerating innovation.

To effectively navigate the evolving landscape of traffic management, European road operators should adopt a proactive and strategic approach to the digitisation of traffic rules and regulations.

4.8 Future of physical signs and markings

In the near future, with advancements in new technologies for localization and navigation in autonomous vehicles, the importance of road markings and signs might slightly diminish. Road markings, similar to road signs, will increasingly rely on digital support and become hybrid. However, these changes will not result in the complete disappearance of road markings and signs in the foreseeable future.

The standardisation of traffic rules and regulations has been started however it will still take another 2 years to fully develop the standards and start implementation. The development of HD maps is ongoing, however, it is primarily controlled by HD mapping organisations who works with their proprietary formats. A lot of progress need to be made towards its standardisation and interoperability. On the other hand, road operators also need to initiate digitalisation within their processes and data with focus on improving the quality, coverage, and freshness of the data.

Current mobility technologies depend on road markings and signs, and it is anticipated that certain highly automated systems will continue to utilize them for the foreseeable future. Furthermore, advanced road marking and signs systems have the potential to address the challenges posed by camera technology and offer opportunities for innovation. These systems can also ensure reliable detection by camera sensors (Tengilimoglu et al., 2023).

Physical road markings will remain necessary until human-driven vehicles are entirely phased out from the road network. Additionally, autonomous vehicles (AVs) can benefit from

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[28] https://etsc.eu/new-legislation-will-boost-availability-of-digital-speed-limit-information/

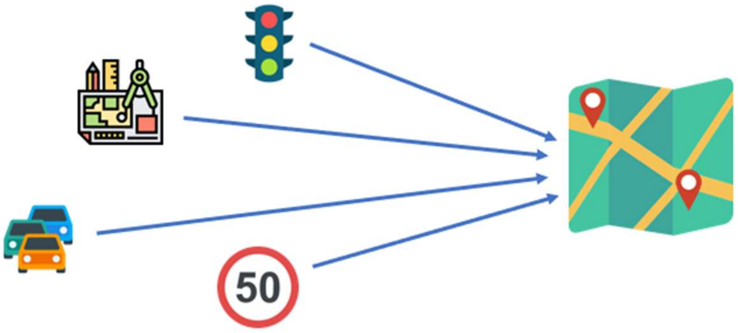
integrating physical road markings and signs with their digital counterparts in maps, enhancing their operational robustness. It is also noted that high-definition maps may not be available for many cities during the initial stages of AV implementation. Thus, in mixed traffic, as human drivers will retain the ability to control vehicles until fully autonomous vehicles become widely adopted, road markings will continue to be a crucial component of infrastructure and will maintain their significance for the foreseeable future (Tengilimoglu et al., 2023).

5 Use cases

This section reports on two use cases within task 3.5.

5.1 *Use case 1: HD maps*

Flow of information from BIM systems that record information of the roads as asset to, HD Maps in the vehicles for new road sections in order to prepare the (new)digital + physical infrastructure for automated transport. (based on DROIDS deliverable D3.3)



5.1.1 Recap: BIM information reuse (D3.3)

The DROIDS deliverable D3.3 explored the potential of using BIM digital representations for a comprehensive digital twin that addresses the entire life cycle of road infrastructure, rather than supporting it only in early stages like design and construction. By leveraging BIM data from the initial design stages and transferring it in a structured format to the operational phase like asset management, the aim is to reduce the need for redundant data capture and create a more cohesive and informed digital twin. It also provided a stepwise plan for the recycling and expansion of BIM representations.

Current state of BIM Information Maintenance among road operators

Road operators across Europe are increasingly adopting BIM to enhance project delivery, improve collaboration, and optimize asset management. However, the level of BIM maturity varies significantly among different countries. While some road operators, like *Ireland*, are in the early stages of BIM implementation, focusing on developing policies and standards, others, such as *Belgium*, have more advanced practices, utilizing BIM models from the design phase through to construction and aiming to extend their use to asset management.

Despite these advancements, several common challenges hinder the effective maintenance of BIM information. These challenges include the lack of standardized data, difficulties in data sharing and integration, and resistance to change. For example, in *Ireland*, the manual approval process and limited use of a CDE hinder efficient information exchange. In *Denmark*, while BIM models are used, there is a disconnect between different project phases, and the lack of data dictionaries limits data standardization. *Finland* faces challenges in ensuring data quality and utilizing historical data. *Belgium*, while making progress, faces resource limitations and market readiness issues.

State of OTLs utilisation within road operators

The utilization of OTLs for BIM information management varies significantly among road operators. Some, like *Belgium*, have well-developed and integrated OTL systems. AWV in Belgium boasts a comprehensive OTL that covers the entire asset lifecycle, encompassing data flow, signal flow, and asset locations. They continuously improve their OTL based on user feedback and best practices. Other road operators, like *Ireland*, are in the early stages of OTL development. TII in Ireland is currently creating data dictionaries and OTLs, but policy implementation is still pending. There are also cases where road operators haven't adopted OTLs at all. *Denmark*, for example, currently relies on a project-wise approach with a naming convention for BIM information management. This lack of standardization poses challenges in data integration and future OTL development.

The focus of OTL extension also differs among road operators. *Belgium* is actively expanding its OTL to include more asset types and integrate dynamic information like sensor data. *Finland*, on the other hand, is currently prioritizing information standardization but has plans to explore OTL extension for digital twin creation in the future. This highlights the need for road operators to consider their specific needs and priorities when developing and extending their OTLs.

BIM information reuse within road operators

Road operators are increasingly recognizing the value of reusing BIM information throughout the asset lifecycle. In *Ireland*, the focus is on validating BIM information to ensure alignment with design intent. *Denmark*, on the other hand, relies on layer-based models, which can limit data reuse. *Belgium* has developed a comprehensive approach to BIM information reuse, extracting relevant data from BIM models and integrating it into an asset database. *Finland* emphasizes the importance of standardizing information transfer and centralizing project data to facilitate reuse.

Key challenges in BIM information reuse include integration and system compatibility, standardization, software dependency, and data quality. To address these challenges, road operators should prioritize standardization, training, and the adoption of flexible software solutions. By implementing these strategies, road operators can improve the efficiency and effectiveness of their asset management processes, leading to better-informed decision-making and long-term sustainability.

Proposed process of BIM information reuse

To effectively recycle BIM representations throughout the full lifecycle of digital twins for road infrastructure, road operators can implement the process as showcased in Figure 23:

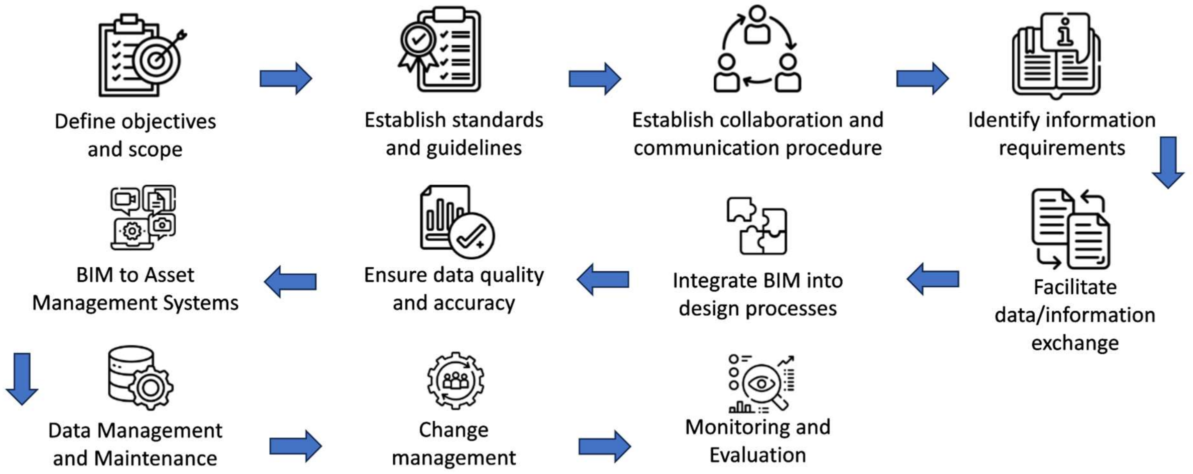


Figure 23: Proposed process of BIM information reuse

a. *Define Objectives and Scope:* Clearly define the goals and scope of BIM reuse, considering data availability, requirements, and stakeholders.

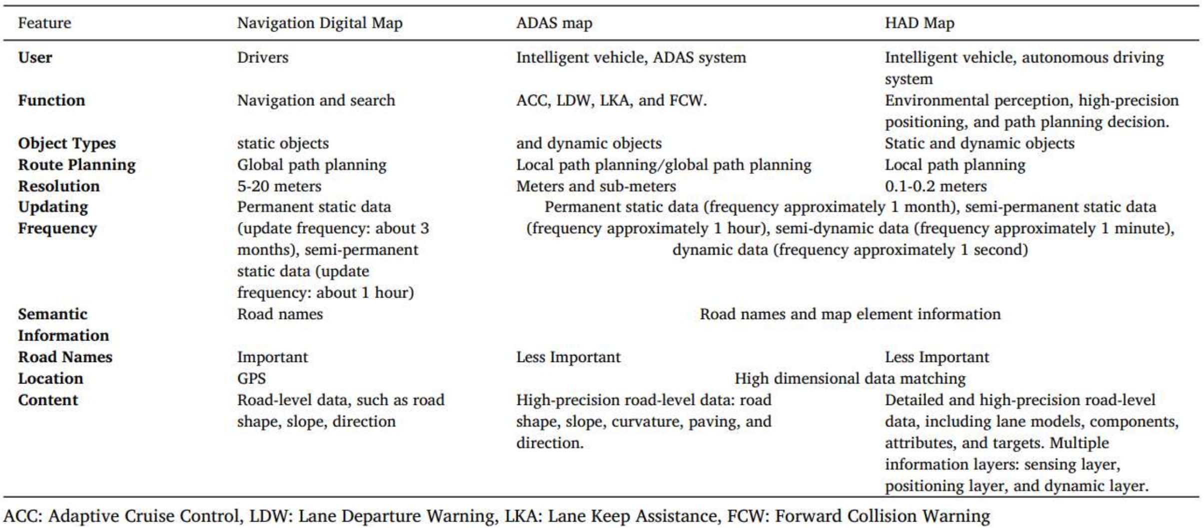
b. *Establish Standards and Guidelines*: Develop and adopt BIM standards, ISO 19650, and OTLs to ensure consistency and interoperability.
c. *Establish Collaboration and Communication*: Foster collaboration between BIM and AIM teams, engage stakeholders, and simplify processes.
d. *Identify Information Requirements*: Define and prioritize information requirements aligned with OTL.
e. *Facilitate Data Exchange:* Implement data governance, utilize CDEs, and establish data transfer protocols.
f. *Integrate BIM into Design Processes:* Collect and standardize BIM data, incorporate BIM from early stages, and link BIM models to OTL.
g. *Ensure Data Quality:* Implement quality control procedures, validate data against OTL, and conduct data audits.
h. *Integrate BIM with Asset Management Systems:* Develop data migration strategies and integrate BIM data to enrich asset management systems.
i. *Data Management and Maintenance:* Ensure continuous data updates, quality assurance, and effective change management.
j. *Monitoring and Evaluation:* Conduct regular assessments, establish a feedback loop, and plan for scaling.

By following these steps and prioritizing change management, road operators can successfully reuse BIM information to enhance asset management and digital twin development.

5.1.2 **What is a** HD map?

High-Definition (HD) maps are machine-readable and centimetre level precise digital representation of the physical infrastructure that can be used by the cooperative, connected, and automated mobility (CCAM). These maps are not intended for general navigation by human drivers but are specifically designed for machines, serving as a detailed and precise representation of the physical world. The data embedded in HD maps goes beyond basic road geometry, encompassing elements such as road shape, road markings, traffic signs, barriers, lane lines, curbs, traffic signals etc. (Odukha, 2023). Table 10 showcases the differences between Navigation, ADAS and HD maps.

Table 10: Differences between Navigation, ADAS, and HD maps (Yang et al., 2024)



Feature	Navigation Digital Map	ADAS map	HAD Map
User	Drivers	Intelligent vehicle, ADAS system	Intelligent vehicle, autonomous driving system
Function	Navigation and search	ACC, LDW, LKA, and FCW.	Environmental perception, high-precision positioning, and path planning decision.
Object Types	static objects	and dynamic objects	Static and dynamic objects
Route Planning	Global path planning	Local path planning/global path planning	Local path planning
Resolution	5-20 meters	Meters and sub-meters	0.1-0.2 meters
Updating Frequency	Permanent static data (update frequency: about 3 months), semi-permanent static data (update frequency: about 1 hour)	Permanent static data (frequency approximately 1 month), semi-permanent static data (frequency approximately 1 hour), semi-dynamic data (frequency approximately 1 minute), dynamic data (frequency approximately 1 second)	
Semantic Information	Road names	Road names and map element information	
Road Names	Important	Less Important	Less Important
Location	GPS	High dimensional data matching	
Content	Road-level data, such as road shape, slope, direction	High-precision road-level data: road shape, slope, curvature, paving, and direction.	Detailed and high-precision road-level data, including lane models, components, attributes, and targets. Multiple information layers: sensing layer, positioning layer, and dynamic layer.

ACC: Adaptive Cruise Control, LDW: Lane Departure Warning, LKA: Lane Keep Assistance, FCW: Forward Collision Warning

Combined with vehicle sensors such as GPS, LiDAR, cameras, IMU etc., HD maps can enable ADS with better perception, planning beyond sensor range, determining precise location, contextual awareness, and local knowledge of traffic rules. In effect, HD maps can contribute to enhanced positioning and control for automated vehicles, with the possibility of increasing their ODD. (RoboticsBiz, 2024, CEDR MANTRA Deliverable D4.2, 2020, Malone et al. 2019). As an example, HD maps function much like a human driver's memory of the road, providing vehicles with a long-range view that allows for proactive anticipation of trajectory changes rather than merely reacting to short-range sensor inputs. Figure 24 provides an overview of various core components of Automated Driving and their reliance on HD maps.

The term HD maps is quite recent and widely accepted in CCAM industry (Liu et al., 2020). Despite the widespread acceptance of HD maps as a fundamental component of CCAM, a formal standard or set of guidelines specifying their information content and representation is currently absent. (Hubertus et al., 2019; Ebrahimi Soorchaei et al., 2022). Numerous standard institutes and companies are developing their unique map standards.

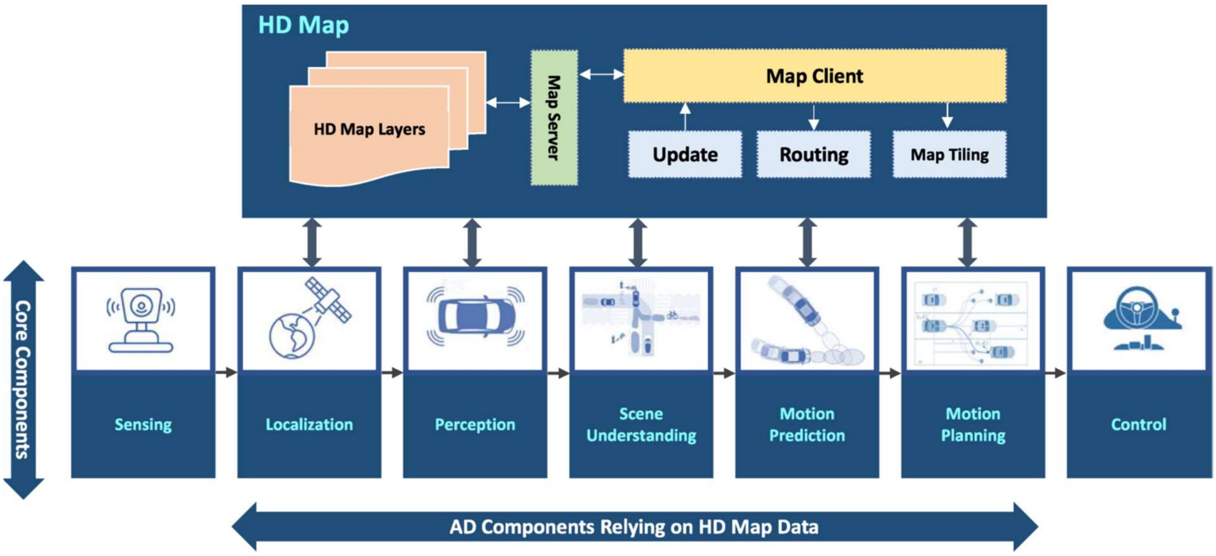


Figure 24: Standard components in modern AD (Automated Driving) system architectures and its reliance on HD maps (Elghazaly et al., 2023)

HD maps do not only contain static information but can also contain dynamic information such as traffic lights, real time traffic information, weather, speed limits, etc. which allows ADS to make informed decisions. As HD maps closely represent the physical environment, it aligns well with the definition of digital shadow as defined in DROIDS Deliverable D2.1-3.1 (Soni et al., 2024).

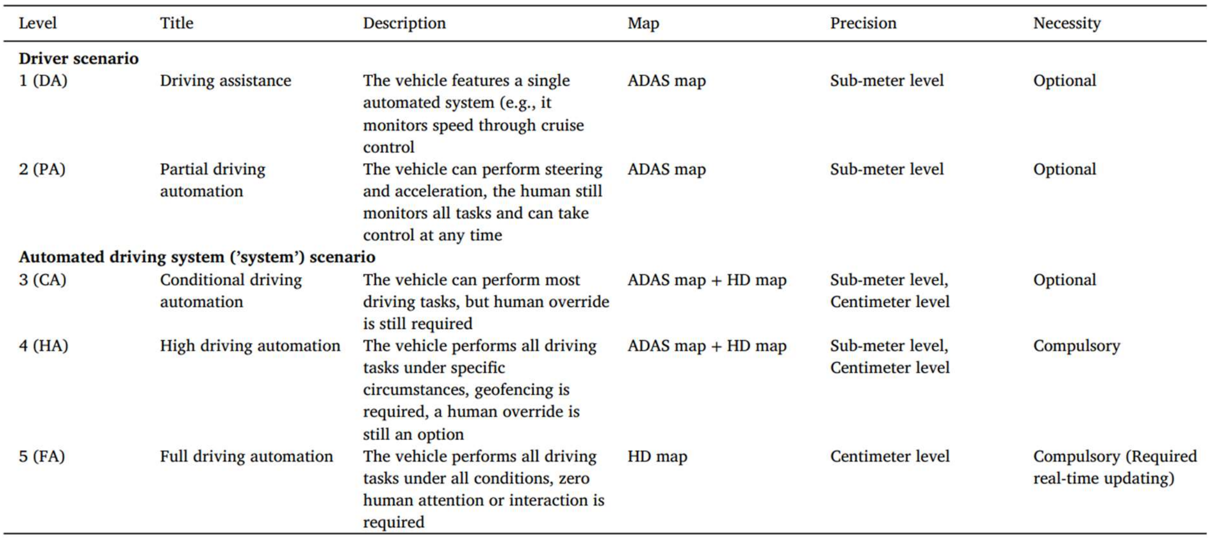
5.1.3 Growth and adoption of HD map

The geographical coverage of HD maps for automated vehicles is has seen significant expansion over the past years. For instance, TomTom's Orbis Maps reportedly covered 86 million kilometres of roads as of January 2024 (TomTom, 2024). Additionally, NVIDIA's mapping platform aimed to cover approximately 482,803 kilometres across key regions by 2024 (NVIDIA, 2024). Dynamic map platform announced their expansion of HD maps in 16 countries within Europe with a total of 270,000 km of motorways and provincial roads (Dynamic map platform, 2024).

The adoption of HD maps is closely linked to the level of automation in vehicles. Yang et al. (2024) presented the requirement of different levels of map for different levels of driving autonomy as showcased in Table 11. While lower levels of autonomy, such as basic ADAS features, can function without HD maps, their integration can significantly enhance the safety and smoothness of these systems. OEMs increasingly recognizing the importance of onboard

HD maps for self-driving systems that go beyond Autonomy Level 2 (Odukha, 2023). In semi-autonomous vehicles (Level 2-3), HD maps are being utilized for features like adaptive cruise control and lane-keeping assistance, providing more reliable and comfortable driving experiences.

Table 11: Necessity of HD maps for different SAE levels of driving automation (Yang et al., 2024)

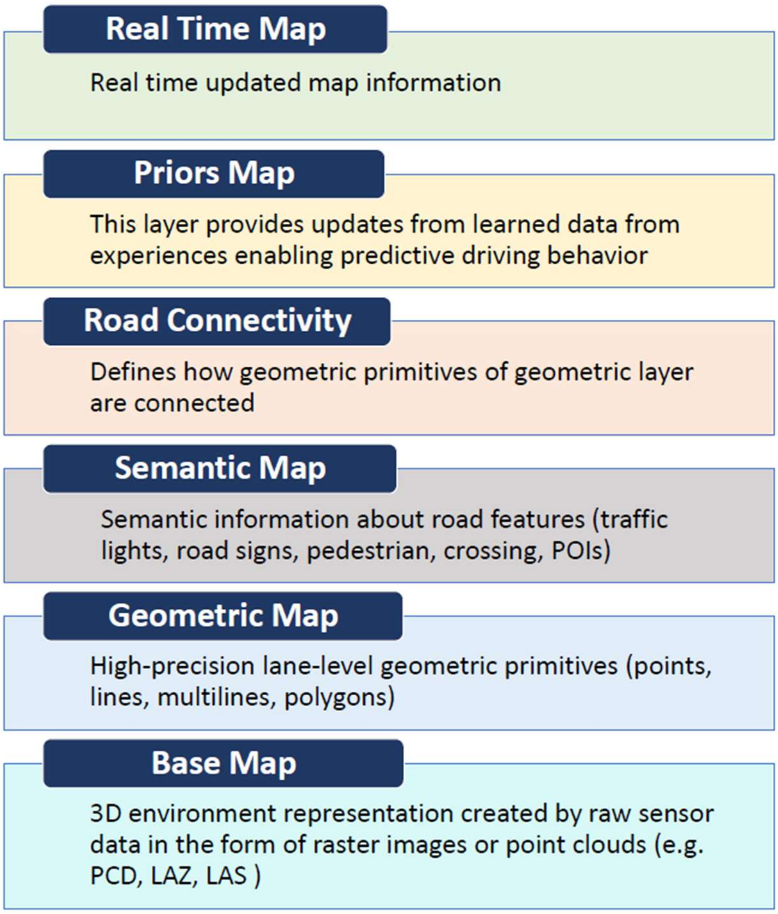


Level	Title	Description	Map	Precision	Necessity
Driver scenario					
1 (DA)	Driving assistance	The vehicle features a single automated system (e.g., it monitors speed through cruise control	ADAS map	Sub-meter level	Optional
2 (PA)	Partial driving automation	The vehicle can perform steering and acceleration, the human still monitors all tasks and can take control at any time	ADAS map	Sub-meter level	Optional
Automated driving system ('system') scenario					
3 (CA)	Conditional driving automation	The vehicle can perform most driving tasks, but human override is still required	ADAS map + HD map	Sub-meter level, Centimeter level	Optional
4 (HA)	High driving automation	The vehicle performs all driving tasks under specific circumstances, geofencing is required, a human override is still an option	ADAS map + HD map	Sub-meter level, Centimeter level	Compulsory
5 (FA)	Full driving automation	The vehicle performs all driving tasks under all conditions, zero human attention or interaction is required	HD map	Centimeter level	Compulsory (Required real-time updating)

However, the role of HD maps becomes absolutely critical for Level 4 and Level 5 fully autonomous driving. At these higher levels of automation, where the vehicle is responsible for all aspects of driving in specific or all conditions, the real-time accuracy and detailed information provided by HD maps are paramount for safe and effective navigation. The precise localization and comprehensive environmental understanding enabled by HD maps are essential for autonomous vehicles to make informed decisions and execute complex driving manoeuvres without human intervention (Sinha, 2024). The growing recognition of these benefits is driving the increasing adoption of HD maps across various levels of vehicle automation, signalling their fundamental importance for the future of transportation (Odukha, 2023).

5.1.4 HD maps architecture

The HD maps are getting more complex due to requirements of ADS, where data from different sources form different layers containing information about driving environment (Garcia et al., 2022). Elghazaly et al. (2023) broke down the HD maps into several layers to present a structured representation of various information as shown in Figure 25.



Real Time Map

Real time updated map information

Priors Map

This layer provides updates from learned data from experiences enabling predictive driving behavior

Road Connectivity

Defines how geometric primitives of geometric layer are connected

Semantic Map

Semantic information about road features (traffic lights, road signs, pedestrian, crossing, POIs)

Geometric Map

High-precision lane-level geometric primitives (points, lines, multilines, polygons)

Base Map

3D environment representation created by raw sensor data in the form of raster images or point clouds (e.g. PCD, LAZ, LAS)

Figure 25: Six-layers generic architecture of HD maps (Elghazaly et al., 2023)

The various layers of HD maps architecture as described by Elghazaly et al. (2023) are as follows:

Base Map: The base map layer of an HD map provides a highly accurate 3D geospatial representation of the environment, including roads, buildings, and other structures, serving as the foundational reference for all other map layers. Created using data from LiDAR, cameras, and GPS/IMU systems, this layer generates dense 3D point clouds from which road and lane features are extracted. Its detailed data is crucial for precise autonomous vehicle localization through point cloud registration, though its creation and maintenance pose significant challenges due to data processing and communication demands.

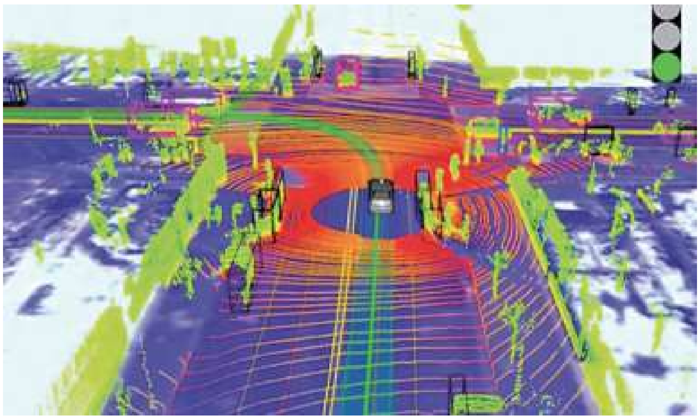


Figure 26: An example of point cloud map captured by sensors in a vehicle (Seif & Hu, 2016)

Geometric Map: While the base map layer offers a detailed 3D representation, it lacks semantic understanding. The geometric layer addresses this by providing precise geometric information about road features like lanes, curbs, and traffic signs, represented using basic geometric primitives (points, lines, polygons). Derived from the base map layer through processes like road segmentation and feature extraction, this layer offers lane-level accuracy crucial for autonomous driving (AD) systems. Specifically, the geometric features are vital for accurate motion prediction of other road users and for safe, geometrically feasible trajectory planning.

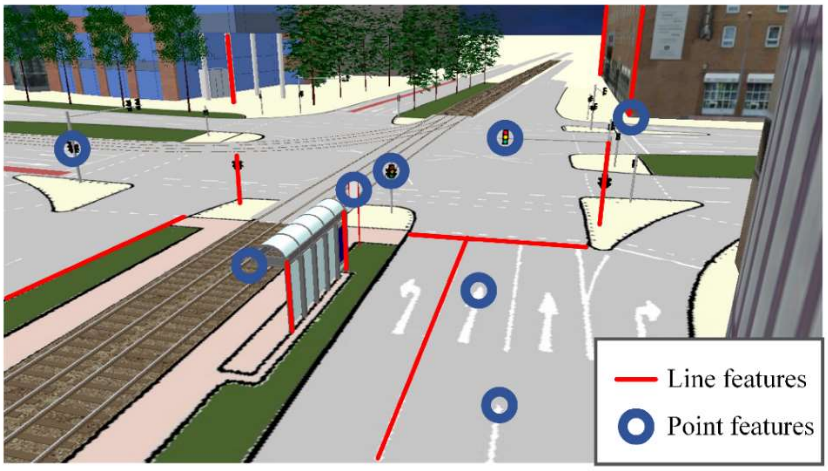


Figure 27: An example of geometric road features (Xiao et al., 2020)

Semantic map: The semantic map layer adds meaning to the geometric map by defining the significance of road features, providing crucial context for autonomous vehicles. It includes information like road and lane types, traffic direction, speed limits, intersections, and traffic signs, enabling the vehicle to understand traffic rules and make safe decisions. Essentially, it assigns semantic labels to geometric features, distinguishing a point as a traffic light versus a stop sign. This layer also includes metadata like road curvature and recommended speed, enhancing the vehicle's situational awareness. While vital for complex decision-making, creating a reliable semantic map requires sophisticated processing steps like scene segmentation and object detection, made increasingly feasible by advancements in computer vision and deep learning.

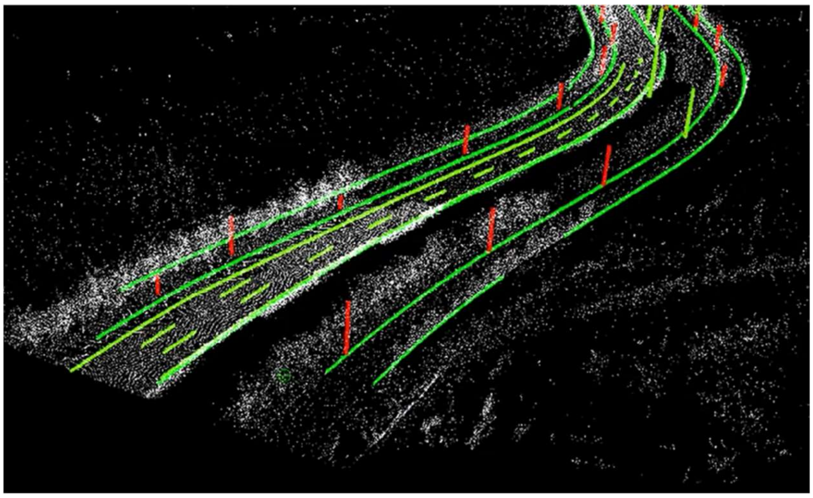


Figure 28: Example of semantic map with different road elements carrying different attributes (Xiao et al., 2020)

Road connectivity: The road connectivity layer details the topology of the road network, specifically focusing on lane-level connections, which is a significant advancement over standard digital maps. It describes how geometric elements, such as lane borders and centerlines, are interconnected, enabling autonomous vehicles to plan legal transitions and manoeuvres at intersections. By defining sequential pairs of geometric and semantic elements and assigning unique identifiers, this layer effectively creates a graph data structure. In this structure, elements are edges, and their connections are nodes, facilitating rapid map querying, searching, and efficient route planning.

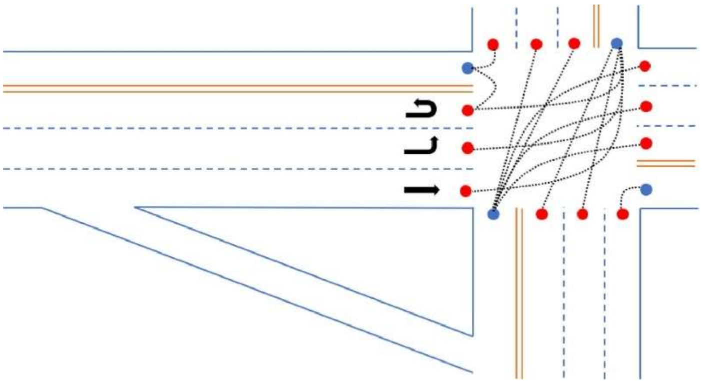


Figure 29: An example of topological map of an intersection where the lane nodes are connected to clearly define the permitted lanes for planning tasks (Yang et al., 2024)

Priors Map: The experimental map layer, also known as the learning layer, captures temporally changing information derived from past experiences. It learns dynamic states like traffic flow, accident zones, and human driving behaviour from fleet vehicle data, enabling more predictive driving. This layer also accommodates temporal road settings, such as parking regulations and occupancy schedules, by analysing sensor readings. Predicting human driving behaviour, which varies across cultures, is a key challenge, but modelling these behaviours from experience is essential for creating universally applicable autonomous driving systems.

Real time Map: The real-time layer of an HD map delivers dynamic, up-to-the-minute environmental data, including traffic conditions and road closures, essential for autonomous vehicle navigation. It integrates data from onboard and roadside sensors, updating the map via crowdsourcing or intelligent infrastructure communication. This layer provides critical information like vehicle speeds, traffic signal status, and road obstacles, enabling real-time, safe, and efficient driving decisions to optimize traffic flow. By capturing changes missed during initial map creation, it also enhances map accuracy. However, maintaining live updates demands sophisticated communication infrastructure and reliable collaboration between data providers and vehicles.

There are also various other architecture of HD maps used by different HD maps providers and research. Mercedes-Benz's Bertha Drive project utilized a three-layer HD map *(Ziegler et al., 2014; The Evolution of the HERE HD Live Map at Daimler, 2018),* while BMW AG opted for a two-layer approach *(Aeberhard et al., 2015)*, separating lane geometry/semantics from localization-specific road markings. Similarly, industry leaders like TomTom and HERE have adopted three-layer HD map architectures (*Soorchaei et al., 2022*). These models, though differing in specific formats, generally encompass lane geometry, road network connectivity, and semantic information *(Liu et al., 2019)*. For example, HERE's HD Live Map comprises a Road Model, an HD Lane Model, and an HD Localization Model *(Soorchaei et al., 2022)*.

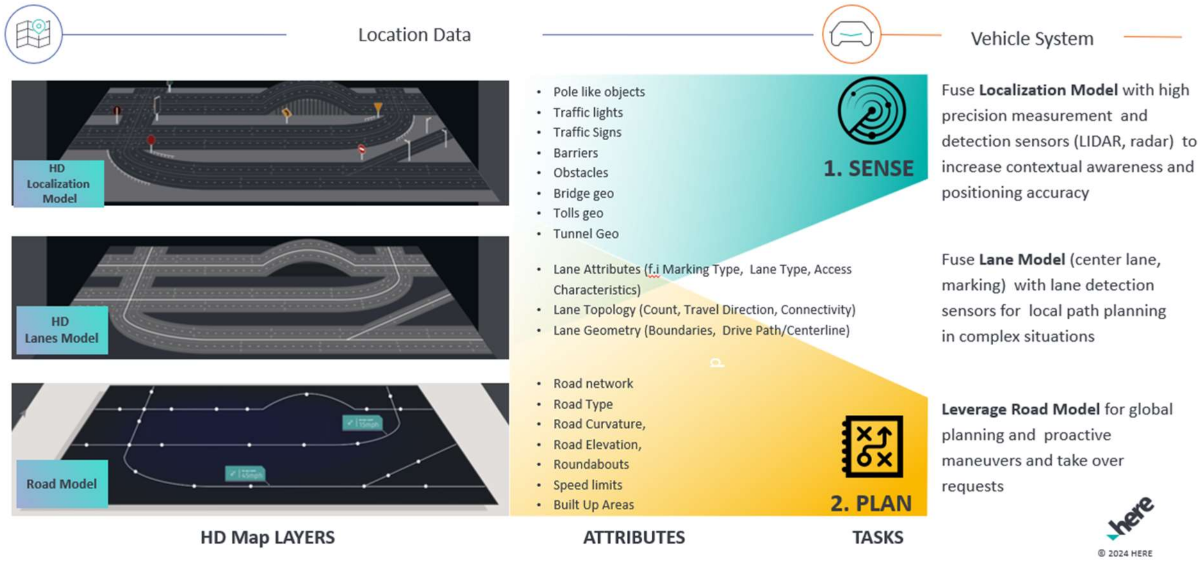


Figure 30:Three layered HD map structure defined by HERE Technologies

Jiang et al. (2019) proposed a seven-layer architecture for HD maps known as Tsinghua map model (TM model) which is illustrated in Figure 31. This architecture is similar to generic architecture as shown in *Figure 25* (with change in order of layers), with an additional layer to represent the dynamic objects sensed by the AVs.

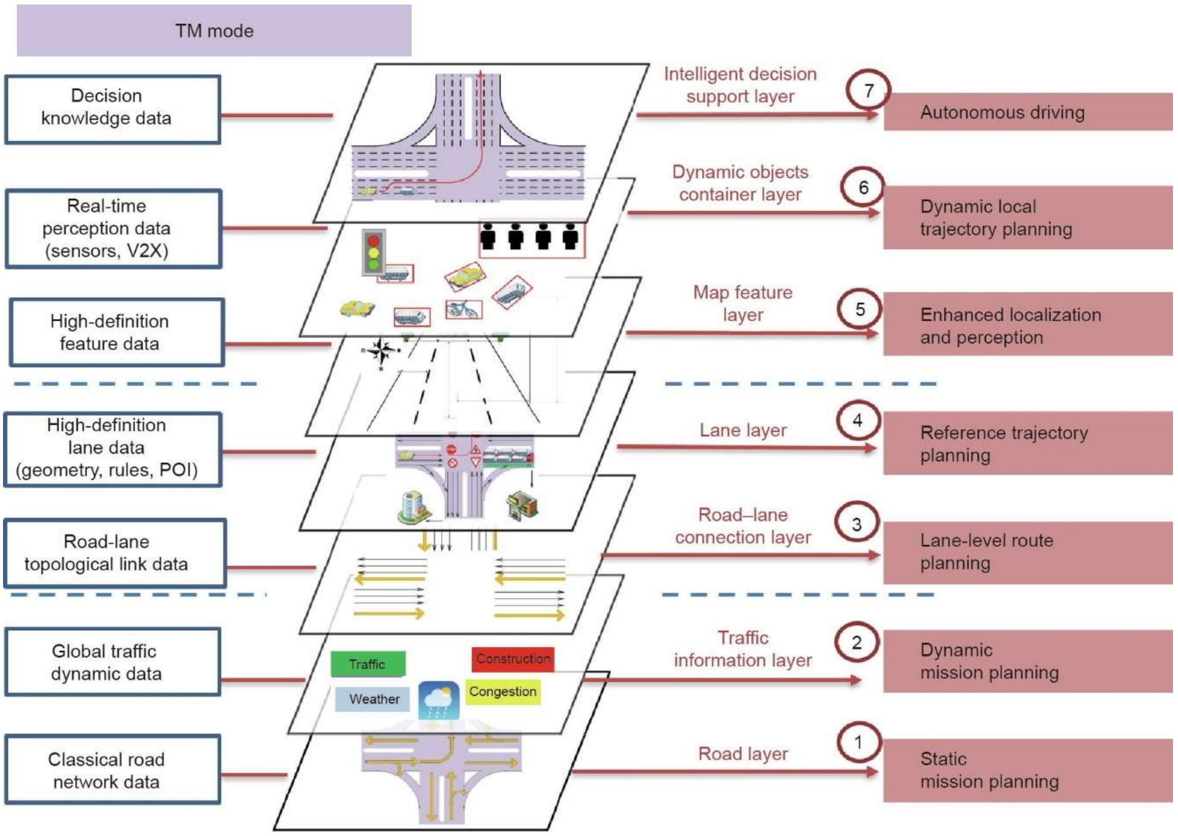


Figure 31: A seven-layer HD map architecture for autonomous driving (Jiang et al., 2019)

This multi-layered map architecture for autonomous driving organizes information from broad road-level data to highly detailed, dynamic local information. Layer 1 provides static road maps, while Layer 2 adds dynamic traffic updates. Layers 3 and 4 bridge the gap between road and lane levels, offering topological connections and detailed lane geometry, respectively. Layer 5 supports self-localization with high-definition feature data. Layer 6 incorporates dynamic obstacle information from various sensors for local trajectory planning. Finally, Layer 7 provides intelligent decision support by embedding driving knowledge and learning driver behaviours, enabling comprehensive autonomous navigation. (Jiang et al., 2019)

5.1.5 HD maps creation

HD maps comprise of validated datasets from various sources which are combined together to provide a broad range of information. The data could come from existing public/private databases along with collection using specialised mapping vehicles using an array of sophisticated sensors, including LiDARs, radars, digital cameras, and GPS systems (Holmes, 2019). Aerial imagery can also contribute to their construction. Maintaining the high accuracy of these maps is a continuous challenge, requiring precise global positioning of features on the Earth's surface and accurate local positioning relative to surrounding road elements.

The BIM information created during the design and construction phase of the (new) road infrastructure could serve as an important data source for HD maps creation as it contains various characteristics of as-built infrastructure. This could ensure reduction in new data capture and harmonisation of information between road operators and HD map providers. The integration of BIM information into HD maps is further investigated in this use case.

5.1.6 HD maps maintenance

Accurate, up-to-date HD maps are essential for ADS to operate safely. Errors in these maps can lead to dangerous decisions by the vehicle. To mitigate this risk, frequent map updates using mapping vehicles are necessary. The constantly changing road environment, due to factors like construction, maintenance, and lane changes, necessitates continuous updates to HD maps (Elghazaly et al., 2022). The process of HD map update involves complex steps, including:

- **Data fusion:** Processing data from various sources and sensors operating at different scales. Road operators could provide data regarding changes in infrastructure using AIM for quick updates to the HD maps.
- **Deviation detection:** Identifying discrepancies between the existing map and newly collected environmental data.
- **Map layer integration:** Incorporating the detected deviations into the appropriate layers of the HD map.

5.1.7 Framework for BIM information reuse in HD maps

Radics et al. (2020) proposed a process flow diagram (Figure 32) for HD map ecosystem within CEDR DIRIZON project deliverable D4.1.

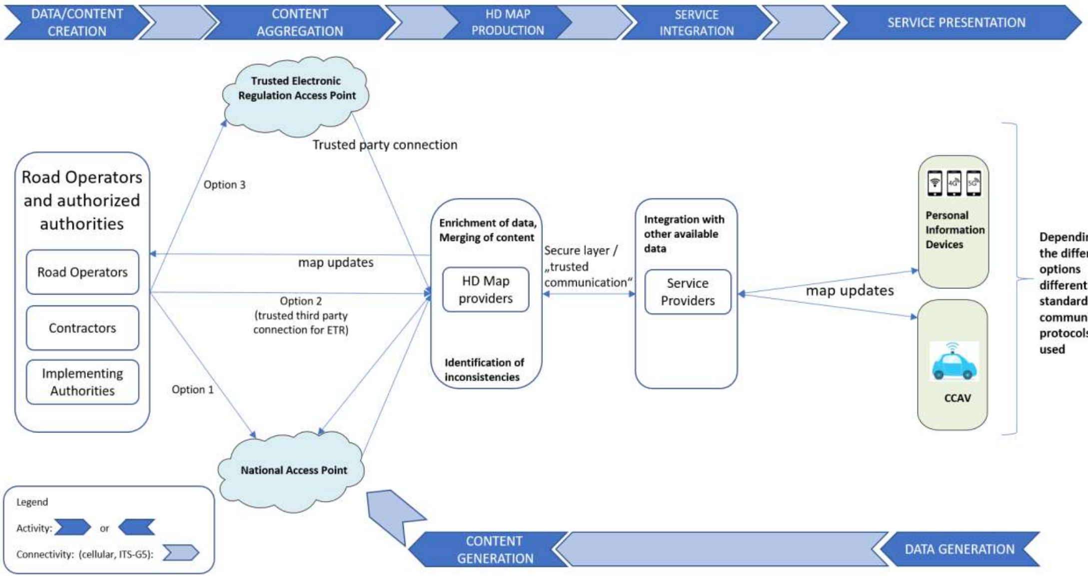


Figure 32: The HD map process flow diagram (Radics et al. 2020)

Within this process flow diagram, road operators and authorized parties contribute essential data, including road geometry, lane details, localization information, and parking data, through a National Access Point or directly to HD Map Providers. Crucially, certified Electronic Traffic Regulation (ETR) data, requiring higher security, is provided through a Trusted Electronic Regulation Access Point or directly to HD Map Providers. These access points, while functionally distinct, can be integrated with the Trusted Electronic Regulation Access Point representing a secure section within the National Access Point.

HD Map Providers integrate the received road, lane, localization, and ETR data, along with regulation certificates, into comprehensive HD maps. These maps are then distributed to Service Providers, who utilize them for navigation and other services, delivering information to both CCAVs and smartphones. A vital feedback loop is established, wherein CCAVs and smartphones report discrepancies between the map data and their sensor readings or human observations, enabling Service Providers to update the maps. Moreover, HD Map Providers provide automated feedback to road authorities via the National Access Point and Trusted Electronic Regulation Access Point, offering insights into data usage and quality, thus facilitating process optimization.

In terms of BIM information reuse, the process flow diagram from Radics et al. (2020) was adapted to include BIM and AIM information within the whole process as shown in Figure 33. A brainstorming session was conducted with the experts within Royal HaskoningDHV to adapt the framework and link BIM/AIM elements to the architecture of HD maps. This adaptation included addition of OTL, BIM data and AIM data as new elements.

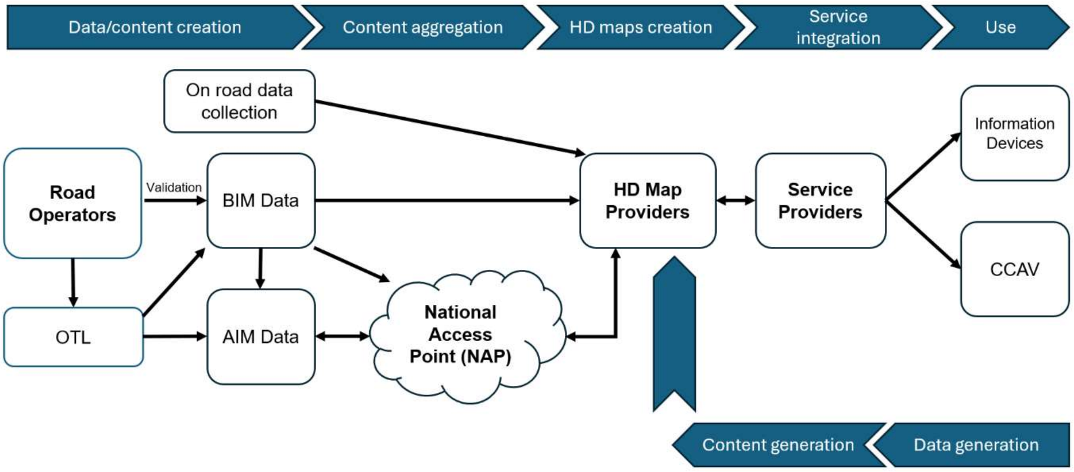


Figure 33: HD map process flow diagram adapted from Radics et al. 2020 for BIM information reuse

This use case is focussed on new road sections. Road operators are responsible for defining OTL which would help in standardising the definitions and data within BIM and AIM models. This standardisation ensures interoperability and promotes more clarity in understanding the information. The road operators can provide the OTL compliant BIM data to HD map providers after its validation. The validation is an important process since the as built infrastructure might differ from the design as reported by road operators in DROIDS deliverable D3.3. The validated BIM information of new infrastructure also feeds into the asset management systems of road operators transitioning into AIM.

The OTL compliant BIM information can be shared by the road operators to the HD map providers either directly or through National Access Point (NAP). In addition, the asset management data can also be integrated into the HD maps via NAP. This would ensure that any changes made by the road operators during the asset management could be updated directly in HD maps.

The HD map providers could use the BIM/AIM information as a data source to enrich the information in HD maps reducing the need for new data capture. This would serve as an additional source over the on-road data collection via vehicles equipped with sensors. Figure *34* Showcases the possibility of integration for various relevant BIM/AIM data into various data layers in generic HD maps architecture proposed by Elghazaly et al. (2023).

The HD maps can thus be shared with service providers for use within CCAV or other information devices.

The feedback loop from vehicle generated data to HD map providers ensures that in case of any discrepancies between digital information and physical infrastructure, the sensor information from the CCAVs can be utilised to update the AIM models as well as HD maps by HD map providers. This capability of utilising data from vehicles for asset management is successfully demonstrated by Road Monitor (ROMO) project by Dutch Ministry of Infrastructure and Water Management (Rijkswaterstaat) in collaboration with Mercedes-Benz[29]. Within ROMO1 initiative, data from the fleet of Mercedes vehicles are used for advanced monitoring of highway conditions such as potential safety hotspots, winter management, and asset management. ROMO2 initiative (a follow up of ROMO1) wishes to utilise data from several service providers to further improve the services and quality.

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[29] https://data.mercedes-benz.com/success-stories/romo

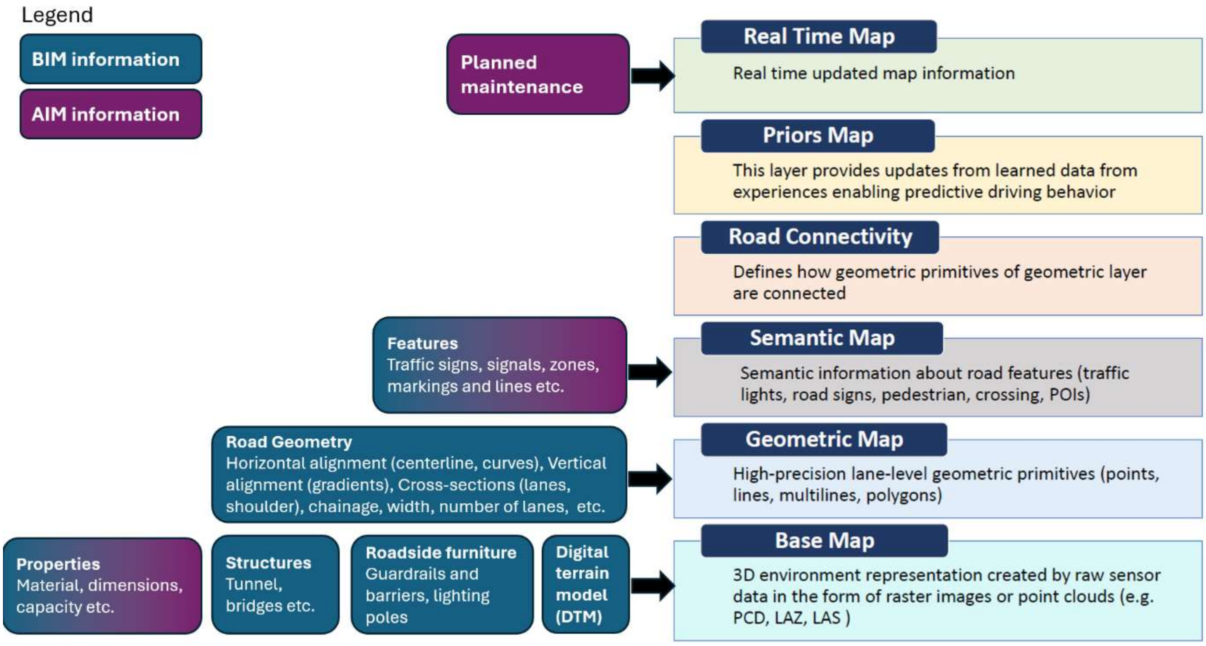

Figure 34: BIM/AIM elements that can be reused within various layers of generic HD maps architecture

In Figure 34, it could be seen that BIM information could mainly feed into the bottom three layers of HD map architecture. The overview of various datasets feeding into various layers is as follows:

Base map layer: The Base map layer of HD maps can be complemented by several elements of BIM and AIM. Digital terrain model (DTM) of infrastructure contains 3D information about existing and proposed ground. DTM can be obtained by performing a high precision LiDAR scan of construction area which gives accurate elevation levels and imagery of the site. DTM can form basis in the HD map to represent the terrain. On the top of DTM, roadside furniture such as guardrails, lighting poles, barriers etc. can add more details. Structures such as bridges and tunnel with their respective 3D BIM digital representations can add more details and attributes to the base map. In addition, various properties such as material, dimensions, capacity etc. could add more context and details to the base map elements. Since some properties for example, dimensions or load capacity might change during the asset management process, it is also linked to the AIM.

Geometric map layer: Various geometric details such as horizontal and vertical alignment, cross section details, lane details etc. from the BIM model can feed into the geometric map layer of the HD maps. This information is usually in form of lines, points, polygons etc.

Semantic map layer: Various Road features such as speed limit signs, pedestrian crossings etc. add rules for driving. These features from BIM model could complement the semantic information in HD maps. Since the features might be updated, add, removed during the asset management phase, this information can also be linked to the AIM.

Real time map: The real time map need integration with sensors and live data stream from road and thus is out of context for BIM information. However, planned maintenance schedules from AIM model can be very well integrated within this layer which can be utilised by the ADS.

These data integrations could help the HD maps in utilising BIM information to enrich metadata in existing infrastructure and could provide a basis of ground truth information for new infrastructure.

5.1.8 BIM information reuse from perspective of HD mapping organisations

In order to validate the framework and possible data integration from BIM/AIM to HD map layers, discussions were facilitated with HD mapping experts from TomTom and HERE Technologies. TomTom highlighted the challenge of integrating BIM data with HD maps due to differences in reference systems and data formats. They emphasized the need for standardized information within BIM models and acknowledged that BIM information is unlikely to replace existing data capture methods for HD maps but can supplement additional information at an early stage. They also noted that daily updates are crucial for automated driving, contrasting with the slower update cycles of BIM data. TomTom suggested that using ground control points in future which can be maintained by road operators could be essential for precise location mapping by AVs and stressed the importance of parallel deployment and development to avoid theoretical pitfalls and speed up adoption.

HERE Technologies discussed their three-layer HD map architecture, which includes the Road Model (geometric information), HD Lanes Model (detailed lane features), and Localisation Model (infrastructure elements like traffic lights and bridges). They emphasized the importance of a feedback loop to gather data from vehicles to update HD maps, ensuring accuracy and up-to-date information. They also highlighted the challenges of processing and handling large amounts of data generated by vehicles, which requires specialized data teams. HERE Technologies currently rely on their own data collection methods, such as LIDAR and vehicle perception data, and do not involve road authorities in their processes. However, they recognize the potential of AIM information linked with HD maps for faster and more efficient updates due to changes in infrastructure from asset management.

Both TomTom and HERE Technologies acknowledged the challenges in getting road authorities to adopt new technologies and standards due to legacy systems and slow processes. They emphasized the need for standardized and high-quality data from road authorities to improve HD maps. HERE Technologies mentioned the potential need for future cooperation with road authorities as HD map coverage expands, emphasizing the importance of timely updates and standardized data. They also noted that while BIM information can be valuable, it needs to be of high quality and standardized.

Regarding the framework, HD map providers think that data emerging from the vehicles might need to be processed by them considering its volume and complexity. Also, they highlighted their doubts regarding sharing of data from road operators directly to HD map providers as the quality, speed and interoperability might not be sufficient. The feedback from HD map providers helped in shaping the framework as in Figure 33.

Ultimately, the discussions with TomTom and HERE Technologies suggest that while BIM information can supplement existing HD map data, it cannot replace physical scans. The quality of BIM/AIM information is crucial, and road operators should develop or implement OTL within their BIM/AIM processes to improve data quality, standardization, and understanding. The feedback loop from vehicle sensors can inform road operators about data discrepancies, aiding asset management and ensuring accurate HD maps.

5.1.9 Conclusion

This use case investigated the possibility of reusing BIM information for HD maps to reduce the need for new data capture. First a literature review was carried out to understand the underlying technology behind creating and maintaining HD maps. Further, the process flow diagram for HD maps creation was adapted during brainstorming session towards reuse of BIM and AIM information. The relevant BIM/AIM information was linked to various HD map layers in HD map architecture.

The collected information and discussions with HD map providers suggested that there is a potential to reuse BIM information in HD maps creation, update and maintenance. The BIM and AIM information can provide additional information in basic three layers in HD map architecture namely: Base map, Geometric map, and semantic map. The possibility of integrating AIM within HD maps will ensure quick and efficient process of keeping HD maps up to date.

However, the quality of BIM / AIM information also plays a major role in adoption of such data within HD map creation processes. HD map providers didn’t express their confidence in using current state of BIM data from road operators due to quality, compatibility and reliability issues. Road operators should develop or implement OTL within their BIM/AIM process to improve quality, standardisation and understandability of the data. Furthermore, validation of BIM information is a crucial step in making sure that the data represents as built environment. The communication of information can take place securely via National Access Points (NAP), whereas the feedback from the sensors in the car can inform HD map providers about discrepancy in data and thus help improve the quality.

5.2 Use case 2: Authoritative information for ALKS

Provision of authoritative information needed for automated lane-level navigation in order to ensure automated vehicles navigate legally through complex traffic environments.

Description of use case

This use case provides an analysis of the critical elements necessary to ensure the safe and legal operation of Automated Lane Keeping Systems (ALKS). The Operational Design Domain (ODD) for ALKS, which defines the specific conditions under which these systems are designed to function, is a foundational concept explored in detail. Complex traffic environments, characterized by high uncertainty and dynamic interactions, present significant challenges for automated vehicles and necessitate a thorough understanding of their definition. While digital information in the form of HD maps is currently available, its capabilities and limitations are crucial considerations. This use case identifies the essential additional digital information required to enhance the safety and legality of lane-level navigation. Furthermore, it examines the relevant international and European standards that underpin the development and deployment of these technologies. Ultimately, the findings of this analysis underscore the need for continued collaboration among regulatory bodies, automotive manufacturers, and digital map providers to realize the full potential of automated lane-level navigation in Europe.

By understanding the ODD of ALKS and defining complex traffic environments, we can identify typical road situations that may pose challenges for ALKS, as drafted RDW (type-approval authority in the Netherlands) for type approval and admission to specific road types in the Netherlands[30]. We will also examine the legal aspects and traffic regulations that govern automated lane keeping, alongside the necessary digital information for ensuring safe and legal lane-level navigation. These elements are crucial for validating and adapting the framework for HD maps and ensuring the effective implementation of ALKS.

Definition of authoritative information

Authoritative information here refers to information that is from official source and regulatory binding and therefore sets the rules and boundaries for the ALKS. Examples of authoritative information are traffic rules and regulation that includes maximum allowed speed for ALKS service and electronic regulation that can include speed limits. Authoritative information is received from a trusted sources which are verified and reliable, such as public authorities and government agencies, or in some cases private operator operating with given legal rights on behalf of the public authority. One example is the Management of Electronic Traffic Regulations (METR) that provides a means for ITS user systems to obtain also authoritative information for the use of surface transport facilities.

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[30] https://www.rdw.nl/en/about-us/development-files/vehicle-automation/alks

5.2.1 What is ALKS?

Automated Lane Keeping Systems (ALKS) is a vehicle technology engineered to manage both the lateral (steering) and longitudinal (acceleration and deceleration) movements of a vehicle over extended periods without continuous input from the driver (*Automated Lane Keeping Systems (ALKS) and Listing of Self-Driving Vehicles - Vehicle Certification Agency*, 2022). During such times, the system assumes primary control of the vehicle, performing the driving task within specific roads and conditions. When explicitly activated by the driver, ALKS must manage the vehicle's movements and continuously monitor driver behaviour, including determining driver availability and attentiveness. The system employs sensors and actuators to maintain the vehicle within the chosen lane and deactivates upon necessary intervention or independent driver action. Automated Lane Keeping System (ALKS) falls under the category of Advanced Driver Assistance Systems (ADAS), which includes other technologies such as advanced cruise control (ACC), automated emergency braking (AEB), forward collision warning (FCW) etc.

These systems are designed to operate primarily on motorway-type roads, under specific conditions. The development and deployment of ALKS are largely governed by UN Regulation No. 157[33], which sets out the uniform provisions concerning the approval of vehicles with regards to these systems. This regulation provides a standardized framework for ensuring the safety and performance of ALKS-equipped vehicles across participating countries. While the title specifically mentions "lane keeping," the regulation encompasses systems that actively control both steering and speed to maintain the vehicle within its lane and adapt to traffic flow (*New UN ECE Regulation on Automated Lane Keeping Systems Published*, 2021).

5.2.2 What is Operational Design Domain (ODD)?

The Operational Design Domain (ODD) defines the conditions under which ADS can safely operate. It sets the boundaries, specifying environmental conditions, road types, and other factors where the autonomous system is designed to function. For example, a self-driving car might have an ODD that includes clear roads, good weather, and moderate traffic conditions. If it encounters heavy rain or a complex city environment, it might be outside its ODD, requiring the human driver to take over (Kees Roelandschap, 2024).

ODD conditions can be spatial, temporal, legal, or environmental. Elements influencing the definition of an ODD include visibility conditions, traffic density, traffic rules (e.g., maximum speed, weight and size restrictions), road sharing signs and equipment, static masks, vehicle behaviour (nominal or in response to events), connectivity needs/capabilities (message content, coverage, reliability), and behaviour of third-party users. In this context, the ODD represents the operating environment within which ALKS can perform the dynamic driving task. The ODD is not just defined by environmental conditions but also due to sensor limitations.

ODD is highly associated with the safety. Tom Leggett et al., 2021 has proposed a framework for safety rating of a vehicle as a function of its ODD. Within the framework, the driving domain of the vehicle under test is defined against the assessment criteria. They developed the ALKS ODD Checklist based on the PAS 1883:2020 ODD taxonomy for an ADS. This ODD checklist informs which tests are to be carried out virtually and validated physically.

5.2.3 Complex traffic environment and ODD for ALKS

Complexity of traffic environment could limit the performance of ADAS systems due to ODD limitations. Complex traffic environments are generally understood as situations characterized by a high degree of uncertainty, dynamic elements, and intricate interactions among various road users and infrastructure (Cheng et al., 2022). This often involve a multitude of factors that can change rapidly and unpredictably, posing significant challenges for the perception, decision-making, and control systems of autonomous vehicles. Several factors that can impact the performance of ALKS and limits its ODD are provided in Table 12.

Table 12: Factors limiting the ODD of ALKS

Factors	Effect
Type of road (divided, undivided)	LKS does not function properly when the road is undivided i.e., without centre lane marking (Infra4AV, 2021).
Lane marking quality	The performance of ALKS heavily relies on the ability to accurately perceive lane markings. Degraded or missing lane markings, especially due to road wear or snow cover, can severely impair the system's functionality.
Lane width	Research has indicated unsafe functioning of LKS below lane width of 2.5 meter (Reddy et al., 2020).
Retroreflectivity of lane markings	A minimum retroreflectivity of 150 mcd/lx/m2 during night under dry conditions is recommended for proper functioning of LKS system (ERF, 2019).
Road curvature	Road curvature must be considered in combination with the speed limit to safely accommodate LKS steering limitations (Reddy et al., 2020)
Contrast ratio of lane marking	A sufficiently high contrast ratio of 3:1 is needed to ensure distinction between marking and pavement (ERF, 2019).
Presence of intersections	In the presence of an intersection, LKS does not function properly. Road geometries such as intersections, roundabouts, and merging lanes, require sophisticated navigation and interaction strategies (Malik et al., 2023).
Type of horizontal curve (linear, parabolic, spline etc.)	The performance of LKS may vary depending upon the type of curve. For example, S curves might be difficult to navigate through.
Lane marking width	A minimum of 15cm width of road markings is recommended by ERF (2019).
Type of lane markings (continuous, discontinuous, etc.)	Different style of lane markings might result in difference in the performance of the LKS.
Lane marking disturbances	Temporary lane markings near work zone or distracting lines such as asphalt repair patches may influence the functioning of ALKS (Reddy et al., 2020).
Lane drops / lane additions	Lane drops and additions often require a lane change which might affect the performance of ALKS.
Lighting conditions	The performance of LKS may also depend on lighting conditions such as sun glare, rain reflection, glare at night etc. (Reddy et al., 2020).
Strength of GPS signals	Inaccuracy in GPS location may result in misalignment

	with any digital location-based information needed for operation of ALKS for example inside tunnels.
Presence of vulnerable road users	Pedestrians and cyclists may exhibit less predictable behaviour compared to other vehicles influencing the performance (Malik et al., 2023)
Weather conditions	Adverse weather conditions, such as heavy rain, snow, or fog, can impair the performance of sensors and reduce overall visibility (Malik et al., 2023). This is particularly seen in night time within the built up area (Reddy et al., 2020).
Dynamic interactions	Dynamic traffic flow, characterized by frequent lane changes, varying speeds, and close interactions between vehicles, also adds to the challenges of navigating these environments safely and efficiently (Malik et al., 2023).

Based on the factors indicated in Table 12, several challenging road situations for ALKS would include

- *Urban environments* with presence of pedestrians, cyclists, intersections, roundabouts, etc.
- *Construction zones* with reduced lane widths, temporary and unclear lane markings
- Adverse Weather Conditions such as snow, fog, rain, ice etc
- *Complex interchanges and merging lanes* such as entry/exit from motorway, lane drops etc.
- *Tunnels which can degrade GPS signal and present variation in lighting conditions*
- *Emergency vehicles* where ALKS must react appropriately to allow them to pass.

These challenging situations highlight the fact that current ALKS technology is primarily designed for relatively structured and predictable motorway environments. Expanding the ODD to encompass more complex scenarios would require progress in sensor technology, artificial intelligence, mapping capabilities, and regulatory frameworks.

5.2.4 ODD for ALKS from regulatory perspective

The legal and regulatory landscape governing ALKS in Europe, primarily shaped by UN Regulation No. 157[33] and its national implementations, sets the boundaries for deployment. UN Regulation No. 157 defines the ODD for an ALKS as the specific operating conditions under which the system is designed to function without any intervention by the driver. These conditions include a range of parameters such as environmental factors, geographical location, time of day, traffic conditions, infrastructure characteristics, speed range, weather conditions, and other relevant constraints. For the assessment of vehicle safety, manufacturers are required to document the ODD available on their vehicles and the functionality of the vehicle within this prescribed ODD. According to the Revised Framework document on automated/autonomous vehicles[31], the ODD documentation should, at a minimum, describe

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[31] Framework document on automated/autonomous vehicles, https://unece.org/info/publications/pub/365097

the roadway types, geographic area, speed range, environmental conditions (weather as well as day/night time), and other domain constraints. These regulatory definitions emphasize the need for a clear and comprehensive description of the conditions under which ALKS is intended to operate safely.

Roadway types are a primary parameter, with current ALKS primarily intended for use on motorways (Vehicle Certification Agency, 2022). These are typically high-speed, multi-lane roads with controlled access. Speed limits also play a crucial role. The initial versions of UN Regulation No. 157 limited the operational speed of ALKS to a maximum of 60 km/h indicating its role as a traffic jam assist (InterRegs, 2021). In January 2023, UNECE extended regulation number 157 for ALKS, allowing highly automated lane changes and extending the speed range to 130 km/h[32]. Environmental conditions are another critical aspect, encompassing weather limitations such as restrictions on operation during heavy rain, fog, or snow, as well as visibility constraints related to day or night time (TNO, 2024). Traffic conditions also define the ODD, including the density of traffic and the types of road users present. For instance, UN Regulation No. 157 currently restricts the operation of ALKS to roads where pedestrians and cyclists are prohibited. Geographical limitations specify the countries or regions where the ALKS has been certified and validated for safe operation (Vehicle Certification Agency, 2022). Finally, infrastructure characteristics, such as the presence of a physical separation between opposing traffic flows, are often a requirement for ALKS operation under regulations like UN No. 157 (InterRegs, 2021). These parameters collectively define the specific operational context for ALKS, highlighting the currently constrained nature of its intended use, primarily focusing on controlled motorway environments.

5.2.5 Regulatory landscape for ALKS

The primary regulatory framework at the European Union level governing Automated Lane Keeping Systems (ALKS) is UN Regulation No. 157[33]. This regulation establishes a set of technical requirements and testing procedures for the type approval of vehicles equipped with ALKS. Key requirements of UN R157 include limitations on the ODD. Initially, the regulation restricted ALKS operation to speeds up to 60 km/h on highways equipped with a central barrier, where pedestrians and cyclists are prohibited[33]. Subsequent amendments have increased the maximum operational speed to 130 km/h[32].

The UN regulation R157 sets standards for safe functioning of ALKS. Based on the regulation, the following conditions must be met for the ALKS system to be activated:

- A deliberate action by the driver, such as pressing the activation button
- The driver is in the driving seat with their seatbelt fastened
- The driver is confirmed as available
- No failure affects the safe operation or functionality of the ALKS
- The Data Storage System for Automated Driving (DSSAD) is operational
- Environmental and infrastructure conditions allow operation specific to the vehicle, meaning suitable weather and surroundings
- The vehicle receives a positive confirmation of system self-check, indicating the sensing system is operating correctly

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[32] Proposal for the 01 series of amendments to UN Regulation No. 157 (Automated Lane Keeping Systems) https://unece.org/sites/default/files/2022-05/ECE-TRANS-WP.29-2022-59r1e.pdf https://unece.org/media/press/368227

[33] https://unece.org/sites/default/files/2023-12/R157e.pdf

- The vehicle is on roads where pedestrians and cyclists are prohibited and which, by design, have a physical separation dividing traffic moving in opposite directions.

The regulation also requires vehicles to be equipped with a Data Storage System for Automated Driving (DSSAD), which allows relevant authorities to inspect the vehicle's status to review road traffic offences. DSSAD records each time the ALKS is activated or deactivated, and when the vehicle is involved in a collision.

The regulation also mandates the inclusion of “Driver Availability Recognition Systems” to monitor the driver's presence and ability to take back control[32]. If these criteria are not met, a transition demand (request by the system to take over the driving task) should be issued. In addition, the ALKS must have a system to check every 30 seconds if the driver is available to take over control of the driving task, using at least two criteria such as input to driver-exclusive vehicle controls, hand positioning, blink rate, and eye closure. If the driver is detected as unavailable, the system should provide a distinctive warning. If the driver does not demonstrate availability within 15 seconds, the system will issue a transition demand. If the driver successfully demonstrates availability, the ALKS continues to operate.

ALKS must have the capability for the driver to easily override the system. The system is required to provide clear warnings to the driver regarding its operational status and issue transition demands when driver intervention is needed. In situations where the driver does not respond to a transition demand (request by the system to take over the driving task), the system must be capable of performing a minimum risk manoeuvre to minimize risks to the safety of the vehicle occupants and other road users in all situations[32].

Compliance with UN Regulations on cybersecurity (UN R155)[34] and software updates (UN R156)[35] is also *mandatory* for ALKS approval[36]. The type approval process involves virtual simulations of various traffic scenarios, testing of critical scenarios on a closed test track, and a driving test on public roads[33,36]. Recent amendments to UN R157 have expanded its scope to include heavy vehicles and have introduced provisions for lane change maneuvers and enhanced minimal risk maneuvers[32]. These EU-level regulations provide a fundamental framework for the safe and legal deployment of ALKS across Europe.

Several key European countries have been actively involved in the implementation and advancement of regulations for ALKS.

Germany: Germany has taken a leading role in the field, having opened its Road Traffic Act (StVG) for Level 3 systems in 2017 (Mercedes-Benz Group, 2021). This proactive approach allowed Mercedes-Benz to receive the world's first internationally valid system approval for conditionally automated driving based on UN-R157. Their DRIVE PILOT system, initially operating at speeds up to 60 km/h on suitable motorway sections, marked a significant milestone. Germany's early adoption and implementation served as a benchmark for other European nations.

France: France has also been a key player, collaborating with Germany in the development of ALKS testing protocols[37]. The national implementation in France aligns with the broader EU

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[34] https://unece.org/transport/documents/2021/03/standards/un-regulation-no-155-cyber-security-and-cyber-security

[35] https://unece.org/transport/documents/2021/03/standards/un-regulation-no-156-software-update-and-software-update

[36] https://www.rdw.nl/en/about-us/development-files/vehicle-automation/alks

[37] https://wiki.unece.org/download/attachments/92013066/ACSF-25-08%20%28FR%20GER%29%20DRAFT%20ALKS%20Testing%20protocols%20presentation.pdf?api=v2

adoption of UN R157. France's active involvement in defining the technical requirements and testing methodologies underscores its commitment to ensuring the safety and reliability of ALKS.

United Kingdom: The UK has implemented UN R157 and has established a process for listing vehicles capable of 'safely driving themselves' under the Automated and Electric Vehicles Act 2018 (“Automated Lane Keeping Systems (ALKS) and Listing of Self-Driving Vehicles - Vehicle Certification Agency,” 2022). For a vehicle to be listed, it must be approved to UNECE R157 and include the UK within its ODD. The Vehicle Certification Agency (VCA) conducts thorough reviews to ensure compliance with UK traffic rules and sufficient validation within the UK's specific context.

Netherlands: The Netherlands, through its type approval authority RDW, plays a crucial role in the type approval process for ALKS[36]. RDW monitors the implementation of UN R157 and related regulations on cybersecurity (R155) and software updates (R156). RDW is also actively involved in developing testing methodologies and scenarios for automated driving systems, contributing significantly to the overall framework for ALKS deployment in Europe (TNO, 2024).

These national implementations demonstrate a general trend towards adopting and adapting the EU-level regulations for ALKS. While there is a common foundation in UN R157, individual countries may have specific interpretations or additional requirements based on their national legal frameworks and priorities.

5.2.6 Liability and responsibility

The legal framework surrounding automated driving systems like ALKS introduces a significant shift in liability and responsibility compared to traditional driving. For Level 3 automated driving, such as that defined by UN R157, liability can be transferred from the driver to the car manufacturer under specific circumstances[33]. This transfer typically occurs when the ALKS is active and operating within its defined ODD. Manufacturers are therefore responsible for ensuring the safe operation of the system under these conditions. However, the driver still retains a crucial role and responsibility. They must remain available to take back control of the vehicle when prompted by the system, for instance, if the ALKS encounters conditions outside of its ODD or in the event of a system malfunction[38]. The regulation mandates driver availability recognition systems to ensure the driver is attentive and ready to intervene if necessary[33]. This shared responsibility model necessitates clear definitions of the system's operational boundaries and the conditions under which the driver must resume control. The data storage requirements in UN R157 also contribute to establishing accountability in the event of incidents involving ALKS-equipped vehicles[33]. As vehicle automation progresses, the legal field must continually refine regulations and clarify the liabilities of both automated systems and human drivers.

5.2.7 Regulatory gaps and challenges

Despite the regulatory efforts to define the ODD for ALKS, several challenges remain in establishing a clear standard and a systematic process for evaluating an automation system's ODD. A few challenges majority of which are related to human factors that are not fully addressed in regulations are as follows:

> **Human-machine interaction:** The current regulations doesn’t address the challenges related to human machine interaction completely. Drivers need to understand the capabilities and limitations of ALKS, and how to use them properly and responsibly. For

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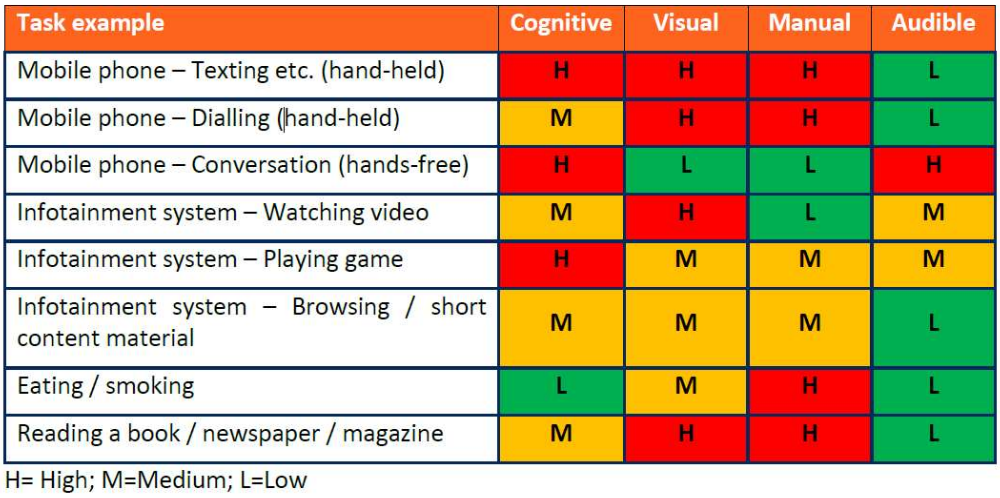
[38] https://auto2xtech.com/regulation-level-3-autonomous-driving-2021/

example, drivers need to know when and how to activate and deactivate ALKS, how to monitor and intervene when necessary, and how to cope with system failures or malfunctions. Drivers also need to trust and feel comfortable with ALKS, without relying too much or too little on them. To address this challenge, ALKS need clear and intuitive user interfaces and feedback mechanisms that can inform and educate drivers and also adapt to their preferences and behaviour (Department for Transport, 2021).

In addition, the warnings generated by the system might overwhelm or confuse the drivers resulting in reduction in their capability to take over the driving task. Different manufacturers have currently a different way and terminology of warning the drivers which must be standardised (Murthyvittala, 2024).

Driver distraction: ALKS regulations require monitoring the driver's availability and driving position. However, this does not account for cognitive distractions like daydreaming or hands-free phone conversations, which can result in the driver not paying attention to the road. Table 13 provides an overview of how various other tasks can impact the driver's cognitive, visual, manual, and audible senses.

Table 13: Impact of NDRT on driver's resources (Louw et al., 2019)



Task example	Cognitive	Visual	Manual	Audible
Mobile phone – Texting etc. (hand-held)	H	H	H	L
Mobile phone – Dialling (hand-held)	M	H	H	L
Mobile phone – Conversation (hands-free)	H	L	L	H
Infotainment system – Watching video	M	H	L	M
Infotainment system – Playing game	H	M	M	M
Infotainment system – Browsing / short content material	M	M	M	L
Eating / smoking	L	M	H	L
Reading a book / newspaper / magazine	M	H	H	L

H= High; M=Medium; L=Low

The driver's ability to respond to a transition demand, which requires taking control of the vehicle within 10 seconds, is crucial. This must be adjusted for various factors such as driver characteristics (age, disabilities), vehicle features, the environment, and the level of user alertness (Lawrence Allan, 2020). The UNECE regulation recommends "sufficient" time should be provided for the driver for transition demand. The term "sufficient time" for transition demand is open for interpretation and need to be different for different situations or maybe different countries (First Approval Requirements for SAE L3 Systems: A Guide ToWP.29 Automated Lane Keeping System (ALKS), 2020).

"Sufficient" time should be calculated considering typical permitted non-driving activities like eating, texting, or watching a film (Insights into Automated Lane Keeping System (ALKS) Test Scenarios, 2023). The attentiveness level of drivers, particularly those with disabilities (e.g., colour blindness, deafness), is not yet thoroughly assessed for ALKS control takeover scenarios (First Approval Requirements for SAE L3 Systems: A Guide ToWP.29 Automated Lane Keeping System (ALKS), 2020).

Behavioural adaptation: ALKS can lead to behavioural adaptations where drivers adjust their environment to fit with their non-driving-related tasks (NDRT), such as moving the seat to use a laptop, listening to music or podcasts via headphones, reclining to relax, and swapping glasses to read. Drivers become more comfortable and trusting in conditional automation systems, leading to various behaviours that could be dangerous for safety (N Kinnear et al., n.d.). For instance, studies show that when the vehicle is under the control of assisting systems like ALKS, drivers like to engage with their smartphones. Other popular tasks include reading books, magazines, and newspapers, using laptops and tablets, listening to podcasts, and applying cosmetics. These activities can be dangerous in terms of safety and timely reaction to unplanned situations (N Kinnear et al., n.d.).

The RAC Foundation believes that despite the rules and limitations of ALKS, some drivers may still use handheld devices while driving due to misunderstanding the law or believing that their chances of getting caught are minimal. The government needs to carefully consider real-world behaviours and act accordingly (Safe Use of Automated Lane Keeping Systems (ALKS): Call for Evidence, 2020) .

Legal aspects: Another challenge for ALKS is addressing the legal and ethical implications arising from their use and impact on society. ALKS raise questions about the liability and accountability of drivers, manufacturers, and regulators in case of accidents or incidents involving ALKS. For example, who is responsible if ALKS fail to prevent a collision or cause a traffic rule violation? How can ALKS be tested and certified to ensure their safety and quality? How can authorities respect the privacy and security of ALKS-generated data for drivers and other road users? To answer these questions, ALKS need clear and consistent legal and ethical frameworks and guidelines that define and regulate their roles and responsibilities.

Drivers should not be unfairly held responsible for the ALKS not behaving appropriately (e.g., stopping unjustifiably without warning) when it is engaged. For example, drivers should be exempt from prosecution for certain traffic rule violations if the vehicle stops unjustifiably while ALKS is engaged. Drivers should only be responsible for taking control when the system requests a takeover (Safe Use of Automated Lane Keeping Systems (ALKS): Call for Evidence, 2020).

RoSPA (The Royal Society for the Prevention of Accidents) agrees that exceptions for unjustified stops for ALKS should be included in traffic rules to ensure drivers are incentivized to take back control when requested. RoSPA believes that the consequences of a vehicle stopping in a live lane could be catastrophic for the occupants and other road users. Thus, drivers should be responsible for resuming control of the vehicle when requested (Safe Use of Automated Lane Keeping System (ALKS), 2020a).

Addressing AI decision making: The European Union's Artificial Intelligence (AI) Act[39] has potential implications for the development and deployment of AI systems used in autonomous vehicles (Güçlütürk et al., 2024). The Act adopts a risk-based approach, classifying certain AI systems as high-risk if they have the potential to significantly affect people's health, safety, or fundamental rights. AI systems deployed in connection with autonomous vehicles, particularly those affecting driving and passenger safety, are likely

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[39] https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai
https://www.europarl.europa.eu/topics/en/article/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence

to be considered high-risk. While the act recognizes that autonomous vehicles are already subject to sectoral legislation like the Type-Approval Framework Regulation (Regulation (EU) 2018/858[40]) and the General Safety Regulation (Regulation (EU) 2019/2144[41]), it aims to ensure that the governance of these AI systems aligns with existing vehicle regulations. The EU AI Act requires that implementation acts adopted under the sectoral legislation take into account the requirements for high-risk AI systems. This could lead to new obligations for automobile manufacturers regarding the transparency, robustness, and accuracy of the AI algorithms used in automated driving systems, including those responsible for lane-level navigation.

Regulation adaptation: The UN regulation for ALKS needs to be more detailed for the EU and even for each country, addressing specific scenarios and various contextual situations such as specific infrastructure, driving habits, signage and marking systems, the presence of cyclists on the road, and the surrounding environment (Insights into Automated Lane Keeping System (ALKS) Test Scenarios, 2023). Each country's regulations and measures related to ALKS should comply with other laws concerning safety, autonomous vehicles, driving behaviours, and highway infrastructures. For example, some traffic rules, especially for highways, should temporarily adjust to accommodate the limitations of ALKS. In addition to modifying some traffic rules for ALKS, road infrastructure should also be promoted and digitized. For instance, clear signage and road markings are crucial for vehicles equipped with ALKS, as they rely heavily on visible lines for lane keeping and signs for speed limit compliance.

Privacy: According to UNECE regulations, the ALKS system require Data Storage System for Automated Driving (DSSAD) which can collect personal data and other information such as the time, place, and speed of driving; the identities of those driving behind or in front of the vehicle; and voice and video recordings. With V2X communication, these systems may interconnect with each other, infrastructure, and the environment. Thus, when collecting personal data, its protection must be considered, including time-limited storage of vehicle data, travelled distances, driving behaviour, and speed. It is essential to determine where the data is stored, how long it can be stored, and who has access to it, especially in case of an accident. Ensuring cybersecurity against system invasion and abuse is also crucial (Sever & Contissa, 2024b). The data collection should focus on long-term storage to serve as potential evidence for regulators and auditors. The Law Commission of England and Wales suggests storing essential data for three years to cover the majority of claims (Insights into Automated Lane Keeping System (ALKS) Test Scenarios, 2023).

Driver training: Manufacturers must offer clear and realistic information in their marketing and advertisements about ALKS capabilities and limitations to prevent exaggeration and misunderstandings. Assessing how manufacturers communicate this technology to consumers is essential.

Manufacturers should ensure that drivers of their vehicles are properly trained to handle them safely. The government should verify that drivers are properly equipped to operate their vehicles safely, either through vehicle-specific coaching or potential changes to the

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[40] https://eur-lex.europa.eu/eli/reg/2018/858/oj/eng
[41] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32019R2144

driver testing and training regime. This could include requiring drivers to certify that they have received and understood the relevant material or creating a new license category specific to operating vehicles with level 3 or 4 automation. The government should also publish guidelines outlining the level of education that should be provided by vehicle manufacturers. This would ensure consistency and could enable training providers to develop additional courses for fleet operators as part of their obligations related to managing occupational road risk.

RoSPA (The Royal Society for the Prevention of Accidents) in the UK suggests that traditional methods of providing information through a vehicle handbook or digital owner's manual are insufficient for vehicles equipped with ALKS. Since the system is designed to allow the driver to disengage from the driving task and imposes new requirements on drivers, they need to fully understand how to operate ALKS safely and how to override the system if necessary. For instance, while ALKS is engaged, applying pressure to the brake pedal will not slow the vehicle but will rather initiate a transition demand (shift of dynamic driving task from vehicle to driver). Drivers are likely to expect that pressing the brake pedal will slow the vehicle (Safe Use of Automated Lane Keeping System (ALKS), 2020b). Therefore, it is crucial that drivers are educated on both the abilities and limitations of the system, as well as their remaining responsibilities.

While some challenges can be mitigated by legislation, manufacturers and software developers must clarify what drivers can and cannot do with ALKS. Only after overcoming legal, technological, and institutional barriers can manufacturers gradually expand the ODD of AVs to include more locations and situations for ALKS.

5.2.8 Digital Information requirements for Lane-Level Navigation

The scope of the study and use case 2 was provision of authoritative information for ALKS. Authoritative information was defined in the beginning of the Chapter 5.2, here in short, as information that is from official source and regulatory binding, received from trusted source such as public authority, government agency or private operator operating on behalf of them.

Digital authoritative information requirements

Digital information that is required for automated lane-level navigation was researched in the study. In addition, automated vehicles information requirements are reviewed as being an umbrella for ALKS and to provide wider scope of possible information requirements.

It should be noted that the information requirements and ODD, specific conditions under which the automated vehicle is intended to drive in the automated mode, between ALKS and automated driving differ due to different environmental and use case conditions, i.e. ALKS limits to motorway environment for lane-keeping, while automated driving systems can be operated in different mixed driving environments, such as complex urban environments. Therefore, automated driving systems and services can have higher requirements for information.

ODD for ALKS in the UNECE (2021) framework include the following minimum information requirements:

- roadway types
- geographic area
- speed range
- environmental conditions (weather as well as day/night time)
- other domain constraints

Furthermore, the UNECE (2021) presents Object Event Detection and Response (OEDR): The automated/autonomous vehicles shall be able to detect and respond to object/events that may be reasonably expected in the ODD. These objects are detected based on the ADS components and architecture which are presented in the Figure 35 below where a high-level classification by Yurtsever et al. (2023).

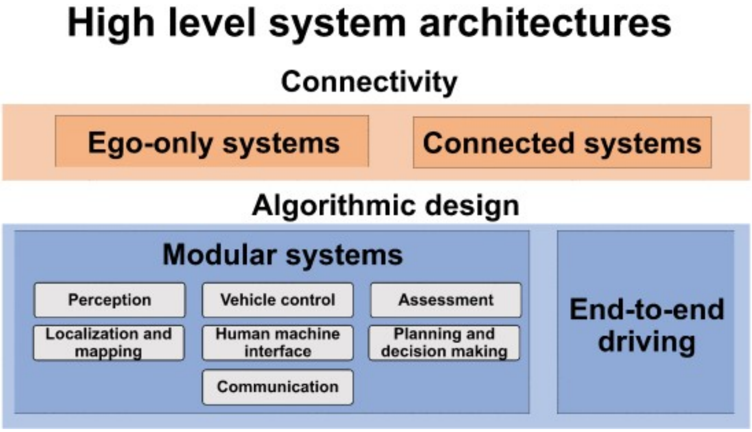


Figure 35 A high level classification of automated driving system architectures (Yurtsever et al. 2023)

In Figure 35 the ego-only system approach always implements automated driving operations on a single self-sufficient vehicle and use of connected systems being optional. Sensors and hardware such as camera, lidar, radar and ultrasonic sensors are the most used for perceiving the environment for dynamic and static objects. (Yurtsever et al. 2023)

Therefore, the ALKS may or may not depend on the modular systems communication from infrastructure and other vehicles. The vehicle may perceive and collect authoritative information such as traffic signs from the environment by itself using sensors and hardware.

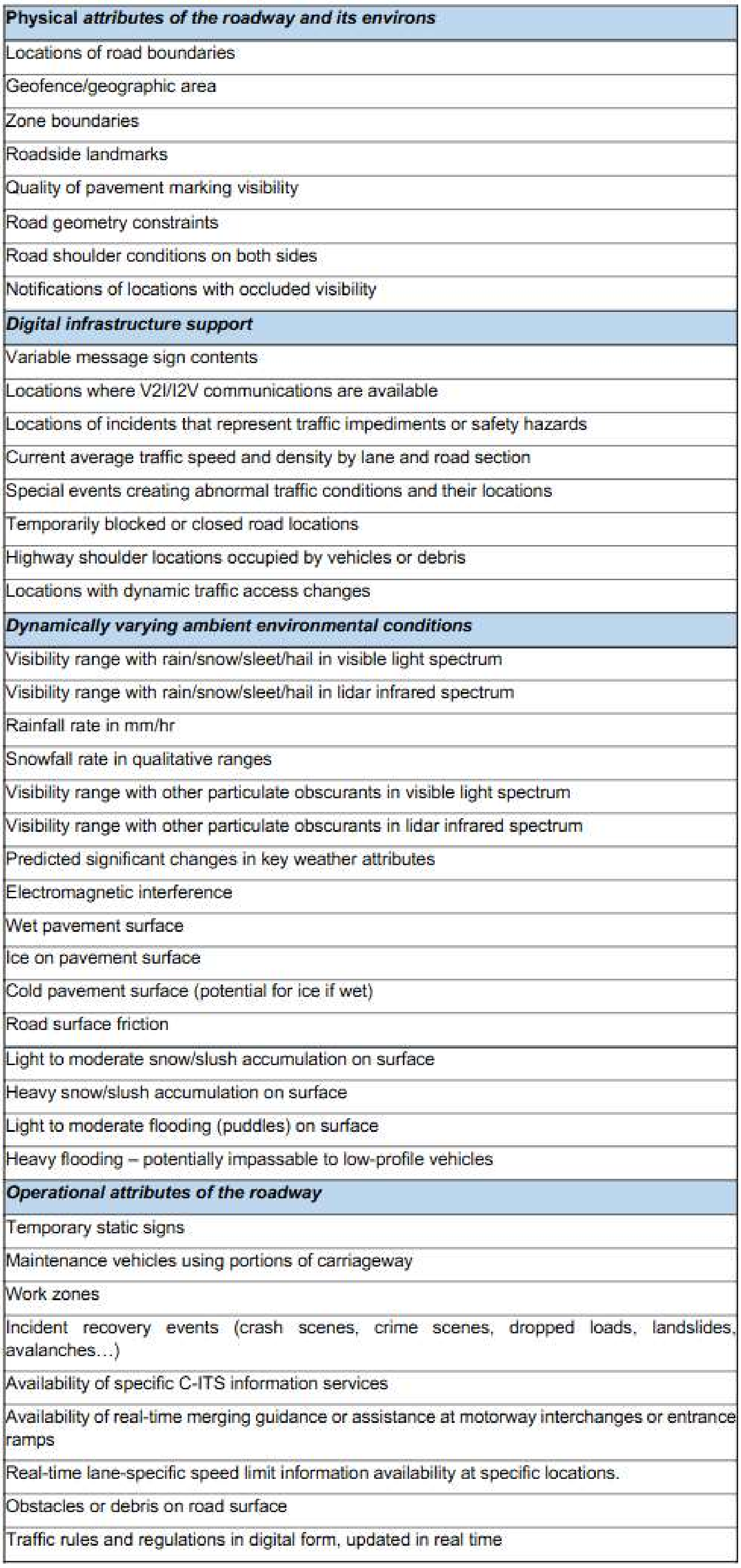
ODD attribute information sources are discussed by Khastgir et al. (2022) who base their evaluation in the BSI PAS 1883 Scenery element. The almost 60 attributes have been divided in to following groups:

- Quasi static physical attributes
- Dynamically changing road surface conditions
- Operational attributes of the roadway
- Digital information support for CAD operations
- Ambient environment attributes (weather, visibility, and electromagnetic environment)
- Roadway operational attributes

The use of the attributes depends on the automated driving system design and its unique ODD, which further can include limitations to ALKS functionality and information requirements as well. Based on the Khastgir et al (2022) ODD attribute groups, presented above, and attributes in the groups, high priority local condition attributes for the vehicle manufacturers (ADS developers) and National Road Authorities in **Error! Reference source not found.** below were studied by Kulmala et al. (2022), which could be further applied by ALKS.

Table 14: High priority local condition attributes for the vehicle manufacturers (ADS developers) and

National Road Authorities. (Kulmala et al. 2022)



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
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

Regulation and legislation create the framework for authorities and authoritative information. Part of the forementioned information are also described as real-time and safety related traffic information in the Intelligent Transport Systems (ITS) framework directive and its delegates acts of

- Commission Delegated Regulation (EU) No 886/2013 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users;
- Commission Delegated Regulation (EU) 2022/670 of 2 February 2022 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the provision of EU-wide real-time traffic information services. (repealing the proceeding Commission Delegated Regulation (EU) No 962/2015).

Many of the above information originates from authoritative sources, which can also originate from legislation, that road authorities and operators collect, maintain and distribute. Physical infrastructure information being the most common information provisioned by the road operators, but also digital infrastructure support, dynamic ambient environment which from traffic management systems and operational attributes of the roadway such as static signs and of course possibly traffic rules and regulations in digital form.

Management of Electronic Traffic Regulations (METR) can be an important part of the navigation to ensure the automated vehicles and possibly ALKS follows traffic rules according to legislation. METR provides a means for ITS user systems to obtain also authoritative information for the use of surface transport facilities. The METR is presented more in detail on Chapter 4.2.

Security and privacy

Security and data protection as well as privacy are key requirements for the provision of authoritative information. Security and privacy risk management and mitigation are already part of the road operator daily data management operation to ensure reliability and trust in the system and information. Security and privacy have been studied and recommendations given in the CEDR funded Call 2022 Data by DROIDS project Work Package 4 Trusted service provisioning and TIARA project (2025)[42].

Digital map data and localization

Digital map data is currently offered by several HD map providers as discussed in 5.1: Use case 1. The presence of these specialized map providers indicates a growing infrastructure aimed at supplying the detailed and accurate spatial data required for sophisticated navigation tasks beyond traditional GPS-based systems.

Despite their advanced capabilities, current digital mapping technologies for lane-level navigation still face certain limitations. The coverage of highly detailed HD maps may not be uniform across all of Europe, potentially focusing more heavily on major highways and densely populated urban areas (Bonte, 2022). Ensuring comprehensive coverage across all road types and geographical regions remains an ongoing challenge. The accuracy and reliability of these maps can also be affected by various factors. Adverse weather conditions, such as heavy rain

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[42] https://aesin.org.uk/tiara/

or snow, can temporarily obscure lane markings and other road features, potentially impacting the map's real-world accuracy (Malik et al., 2023). Similarly, the availability and quality of GPS signals, which are often used in conjunction with HD maps for localization, can be limited in certain environments like tunnels (Malik et al., 2023). The process of creating and maintaining HD maps is also resource-intensive and costly[43]. Keeping the maps up-to-date with the ever-changing road infrastructure and traffic conditions requires significant effort and infrastructure for data collection and processing. Representing and providing timely updates on temporary road conditions, such as those found in construction zones or due to temporary signage, also presents a considerable challenge (Bonte, 2022). While real-time traffic information is often integrated, ensuring its accuracy and reliability across all scenarios is crucial. These limitations highlight areas where further development and improvement are needed to fully realize the potential of digital mapping for safe and reliable automated lane-level navigation in Europe.

Provisioning of information

Provisioning of the information requires interfaced and access points. The forementioned ITS directive and its delegated acts set requirements for the data accessibility which further creates European wide interoperability and supports the use of data in digital twins and representations. The data access shall be from national access point (NAP) set by Member State (Delegated Regulation 2022/670, Delegated Regulation (EU) No 886/2013). Therefore, NAPs are the logical access point for the authoritative information provisioning.

Data quality and accuracy for the provisioning of the authoritative information, which is crucial for the validity and reliability of the information, and the responsibility of the road operator are discussed in the TIARA project results of Kotilainen & Kulmala (2025) which are here summarised in short from the results conclusions:

> *European legislative framework for Intelligent Transport Systems (ITS) is set by the ITS Directive (2023/2661). The ITS Directive requirement for Member States to ensure that where the underlying information already exists, data are made available for geographical coverage for each data type defined in the Directive. These data types can also be exchanged by C-ITS. Requirements for the standards and specifications include C-ITS and safety-related traffic information (which of many C-ITS services are), where the latter includes minimum requirements for the availability and accessibility of accurate data.*
>
> *Therefore, there are no direct technical requirements outside of required data formats (DATEX II, etc.) related to ITS or C-ITS data accuracy nor quality in European legislation. However, Member States are required by legislation to set up NAP, make the data available, communicate inaccuracies (in collaboration), provide parameter of the quality of the data update, and follow minimum quality requirements that are agreed in cooperation with relevant stakeholders (RTTI 2022/670). These are further implemented in the Member State, depending on legislation and policies, by the road operator or National Road Authority (NRA).*
>
> *When a road operator deploys C-ITS services it follows applicable standards and common European harmonised specifications to achieve cross-border interoperability (C-Roads); these standards and specifications include or may include in the future minimum requirements for the data accuracy/quality.*

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[43] https://www.geoweeknews.com/news/tomtom-orbis-maps-now-featuring-immersive-3d-lane-geometry-over-the-global-road-network

Role of the road operator when provisioning the authoritative information has been studied in by the DROIDS project deliverable 2.2 National Road Authority roles in digital twins. The results include general electronic transport regulations use case for digital model, where road operator role was considered active in the maintenance and use stages of life cycle of road infrastructure. Active and passive roles was considered for development of the digital model.

Road operator roles were also presented in the Chapter 4.4 Roles of stakeholders in traffic rule digitisation where the following summary was given:

- Standardisation – Passive role for road operator
- Development/ digitalisation – Active role for road operator
- Operation (Quality & service assurance / Data delivery) – Active role for road operator
- Maintenance (updating rules) – Passive role for road operator

5.2.9 Conclusion

This use case investigated the authoritative information needed for automated lane level navigation by ALKS. Lane-level navigation for automated vehicles, particularly ALKS, requires authoritative digital information from trusted sources like road authorities. This information, encompassing road types, geographic areas, speed ranges, environmental conditions, and object/event detection, is crucial for safe operation. While sensor-based systems can perceive some data, comprehensive ODD attributes, as defined by BSI PAS 1883 and ITS directives, necessitate robust digital maps and real-time traffic updates. These maps, despite advancements, face challenges in coverage, accuracy, and maintenance. National Access Points (NAPs) facilitate data accessibility, emphasizing security, privacy, and data quality. Road operators play active roles in developing, operating, and ensuring the quality of this information, adhering to European standards and regulations, to support reliable and interoperable automated driving systems.

In conclusion, the provision of authoritative information for ALKS is crucial for ensuring safe and legal navigation through complex traffic environments. By understanding the ODD and identifying challenging road situations, we can enhance the capabilities of ALKS. The integration of digital information, such as HD maps, with authoritative traffic regulations will enable ALKS to operate effectively within their defined ODD. Continued collaboration among regulatory bodies, automotive manufacturers, and digital map providers is essential to address the limitations and challenges associated with ALKS. This collaborative effort will pave the way for the successful deployment of ALKS, ultimately contributing to safer and more efficient road transport systems.

6 Conclusion and recommendations

This deliverable presents the findings of work carried out within task 3.4 and 3.5 of DROIDS project. It aimed to explore the digital representation of traffic rules and regulations and report on two use cases: Reusing BIM/AIM information for HD maps and provision of authoritative information needed for lane level navigation by ALKS.

In order to gather information, a comprehensive desk research on the current state of the art of traffic rule digitisation was conducted. The literature review included an analysis of outputs from previous CEDR projects: TM4CAD and DiREC. Based on the findings from the literature review and identified gaps, a workshop with various road operators was carried out to gather information on their priorities and the roles of various stakeholders in traffic rule digitisation. Additionally, a questionnaire with similar content to the workshop was distributed to gather further responses from stakeholders who were unable to attend the workshop.

On the other hand, task 3.5 is focused on reporting on two use cases. The first use case addresses the flow of information from BIM and AIM systems to HD maps for automated transport. For this use case, inputs from DROIDS deliverable D3.3 regarding BIM information reuse were utilized as a starting point. A literature review on HD maps was conducted to understand the underlying mechanisms, architecture, and to explore potential opportunities for BIM information reuse. Based on the findings from the literature review, a brainstorming session with experts at Royal HaskoningDHV was held to adapt the framework and process flow diagram for HD map creation and usage towards BIM information reuse. Furthermore, interviews with HD map providers were conducted to validate the framework and gather additional details from a service provider’s perspective. This use case was further aligned with DROIDS work package 5: Data Strategy.

Based on the information gathered from the research and interviews, the deliverable’s sub research questions mentioned in section 2 are reviewed below:

(RQ12) How can traffic rules and regulations be transformed into a digital and machine-readable representation that enables automated vehicles to understand and follow them on a European level?

This deliverable provided a comprehensive understanding of ongoing standardisation for Management of Electronic Traffic Regulations (METR) under section 4.2. The ongoing METR standardisation initiative promises a structured way to digitise various traffic rules and regulations. Section 4.1.2 identified various traffic rules and regulations with their digitisation potential. It was found that the operational traffic rules (related to the operation of vehicles dictate how vehicles should be driven, including speed limits, lane discipline, overtaking, and right-of-way at intersections) exhibit high digitisation potential. In addition, road signals, sign and marking also showcases high potential for digitisation. Temporary and conditional traffic regulations such as road works, closures, incidents etc also showcased high digitisation potential. Rules related ton specific road user groups such as HGVs, VRUs etc and vehicle/driver compliance rules showcased medium to low digitisation potential.

This deliverable also explored various traffic rule digitisation initiatives. Management of Electronic Transport Regulations (METR) emerged as one of the most relevant standardisation efforts currently being made to digitise traffic rules and regulations. METR enables provision of traffic rules and regulations that machines can understand and trust.

Current Traffic Regulation Orders (TROs) are published as paper documents by authorities or regulators following consultation and approval processes. These documents are primarily text-based legal papers. METR aims to digitise Traffic Regulation Orders (TROs) issued by regulatory body in a machine readable format and enables its distribution through secure channels. Within its scope, METR will support both static rules, which can typically be accessed well in advance of the location, and dynamic rules, which field personnel or equipment might change an instant before reaching a particular location. The METR standard provides and structured and reliable methodology to digitise the traffic rules and regulations. The METR is an ongoing standrdisation effort which might take upto another 2 years to complete.

Several countries are frontrunners in adapting METR to their national standards and digitising traffic rules. Standards Norway has published their first Norwegian METR standard . The UK's Digital Traffic Regulation Orders (D-TROs) mandate also is a big step ahead towards achieving METR digitisation goals.

In order to gain an understanding of traffic rules and regulations deemed important for digitisation by road operators, we asked workshop attendees and questionnaire respondents which rules or regulations would they like to see digitised and in what priority. The opinions about the priority for digitization of traffic rules in view of road operators and other stakeholders varied in a spectrum. Some stakeholders did not specify a certain priority for digitization. Rather, they relied it on the context such as big cities, region, or easiness of digitisation of rules. Some stakeholders specified the digitization of traffic rules in a more generic terms like all formal and informal rules.

From the workshop conversations and analysis, road operators emphasized on prioritising safety critical information in first place. In addition, the information that is required to be digitised under Traffic Regulation Orders (TROs), RTTI/SRTI regulation and ITS obligations were also given priority for digitalisation. The **speed limits** were identified as the highest priority for digitization due to their critical role in safety and the mandate of ISA as per Regulation (EU) 2019/2144. The importance of **dynamic traffic information**, such as variable message sign (VMS) information, was also emphasized. This includes all dynamic information such as dynamic speed limits, dynamic lane closures, traffic information etc. **Planned or unplanned disruptions** such as roadworks and road closures were also considered high priorities for digitisation as these represent safety critical information and sets expectations regarding driving behaviour around disruptions. **Access restrictions** such as access to emission zones was also seen as a low hanging fruit for digitisation. Third priority was indicated toward digitisation of **traffic signs** such as no overtaking, no stopping etc. as play a important role in safe driving. Rules around **incidents** such as reducing speed limit, priority to emergency vehicles etc. were also considered in third priority. Fourth priority rules were more towards heavy goods vehicles (HGV) where **height and weight restrictions** were seen as important rules to be digitised to ensure safety. Lastly, restriction on **carrying dangerous goods** were seen as another important rule for digitisation.

During the workshop and also during the AG meetings, we discussed the roles of various stakeholders in the ecosystem of traffic rule digitisation. Road operators play a multifaceted and crucial role in the lifecycle of digital traffic rules and regulations. They are actively involved in issuing traffic regulation orders, adapting national and regional standards, and provisioning up-to-date, high-quality data for end users during the operational phase. They also contribute to the maintenance of traffic rules and regulations and provide input to ensure standards accommodate local interests. Their activities span from the initial stages of standardisation and digitisation to the ongoing operation and maintenance of the digital traffic ecosystem.

Finally, insights from METR working group and Norwegian Public Roads Administration (NPRA) during their webinar hosted on 25th March 2025, highlighted that road operators should try to be involved with the standardisation process as early as possible. The first step towards getting involved with METR development is to follow the ongoing standardisation process and understand the standards in detail (for example understand the first three parts of ISO standards for METR). Furthermore, participating in standardisation efforts at national and European level would benefit road operators in gaining maturity and knowledge for implementation of METR. Also, the road operators should think from their local perspective on what is required for them. Sharing of specific requirements would also help in shaping METR to a wide variety of situations and use cases.

(RQ13) To what degree will physical traffic signs, signals and markings be needed in a future of automated driving, where rules and regulations are digital and machine-readable?

The transition to fully automated driving will not eliminate the need for physical traffic signs, signals, and markings in the near future. While digital technologies like HD maps and machine-readable regulations are advancing, current mobility systems still heavily rely on traditional infrastructure. Moreover, the coexistence of human-driven and autonomous vehicles necessitates physical cues for safe navigation, especially as HD map coverage remains incomplete and standardization efforts continue. Integrating physical and digital elements creates a more robust and reliable system, enhancing the operational capabilities of autonomous vehicles.

Furthermore, physical road markings and signs address limitations in camera-based detection and offer opportunities for innovation through advanced systems. The phasing out of human-driven vehicles, a process that will take considerable time, is a prerequisite for the complete removal of physical infrastructure. Until then, these physical elements remain crucial for maintaining road safety and order. The standardization of digital traffic rules and regulations is still underway, indicating that the transition to a purely digital system is a gradual process, further emphasizing the continued importance of physical infrastructure.

(RQ14) How can dynamic [regulation] information be described and shared with road users, in combination with the more static regulations?

Section 4.1.2 discussed various traffic rules and regulations that are dynamic in nature. The rules can be dynamic in temporal or spatial context or both. METR also enables provisioning of dynamic traffic regulations which can be issued on by traffic management centre. Magnus Gustin (2024) has proposed a mechanism for sharing the dynamic regulations via METR as shown in Figure 36.

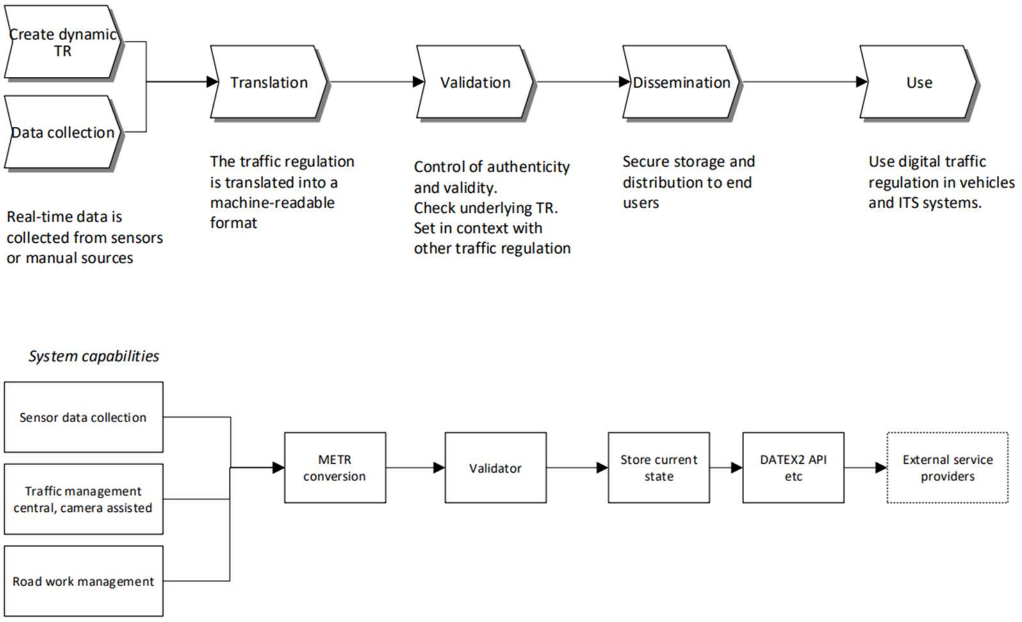

Figure 36: Provision of dynamic regulation (Magnus Gustin, 2024)

Within this proposed framework, the dynamic regulations are based on real time situation on road and applicable dynamic measures based on the situation. This necessitates sensor data collection and sharing of traffic management intervention in place. This real time information requirement highlights the importance of Digital Twin of the road infrastructure.

Recommendations

To effectively navigate the evolving landscape of digitalisation of traffic rules and regulations, HP mapping, and information provision for lane level navigation, road operators are advised to adopt a proactive and strategic approach. Based on the insights from previous sections, following recommendations can be made:

1. **Early engagement in standardization:** Road operators should engage in the METR standardization process as early as possible. This includes actively following the ongoing development and gaining a deep understanding of the relevant standards, particularly the foundational elements outlined in the initial parts of the ISO standards for METR. Participating in standardization efforts at both national and European levels will enhance the operators' maturity and knowledge, facilitating smoother METR implementation.

2. **Local perspective and requirement sharing**: Road operators should thoroughly assess their local requirements and specific use cases for METR. Sharing these specific requirements with standardization bodies will ensure that METR is adaptable to a wide range of situations. Collaboration and knowledge exchange among road operators will promote alignment of interests and ensure interoperability across different regions.

3. **Phased digitalization of traffic rules**: Begin with the digitalization of simple and easily achievable regulations, such as speed limits, which are mandated for the Trans-European Transport Network (TEN-T) by December 2025 and the entire public road network by December 2028. Gradually expand digitalization to include other traffic rules and information signs, following a prioritized approach.

4. **Development of a clear digitalization strategy**: Road operators must develop a comprehensive digitalization strategy that outlines specific objectives, priorities, and timelines for the transformation. Ensure alignment with both national and European Union level initiatives.

5. **Uniform Traffic Regulation Order (TRO) processes**: Standardize and digitize the processes for creating Traffic Regulation Orders (TROs).

6. **BIM standardisation**: Road operators should develop or implement OTL within their BIM/AIM process to improve quality, standardisation and understandability of the data. This would enable opportunities to integrate BIM/AIM data within the HD maps.

7. **Ensuring high-quality infrastructure for Automated Driving Systems (ADS):** Conduct regular assessments of road infrastructure to ensure the effective functioning of ADAS like Intelligent Speed Assistance (ISA). Identify and address issues with both digital information and physical infrastructure elements, such as the visibility and durability of road signs.

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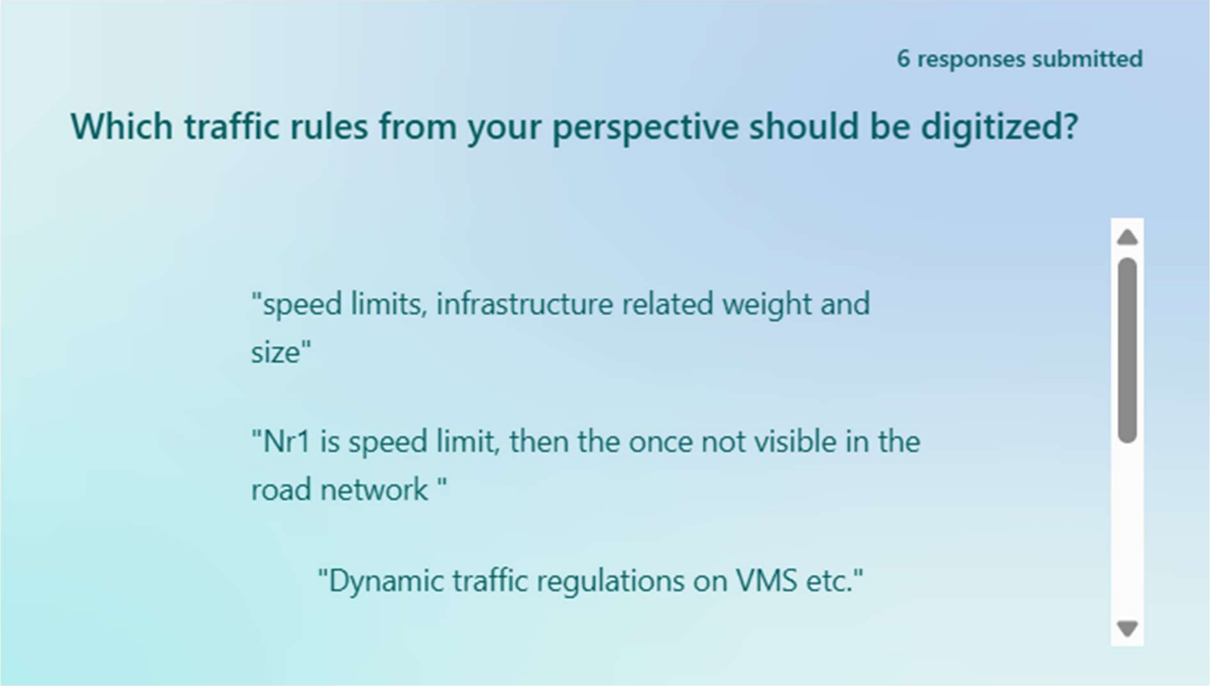
Appendix A: Workshop content and responses



6 responses submitted

Which traffic rules from your perspective should be digitized?

"speed limits, infrastructure related weight and size"

"Nr1 is speed limit, then the once not visible in the road network "

"Dynamic traffic regulations on VMS etc."

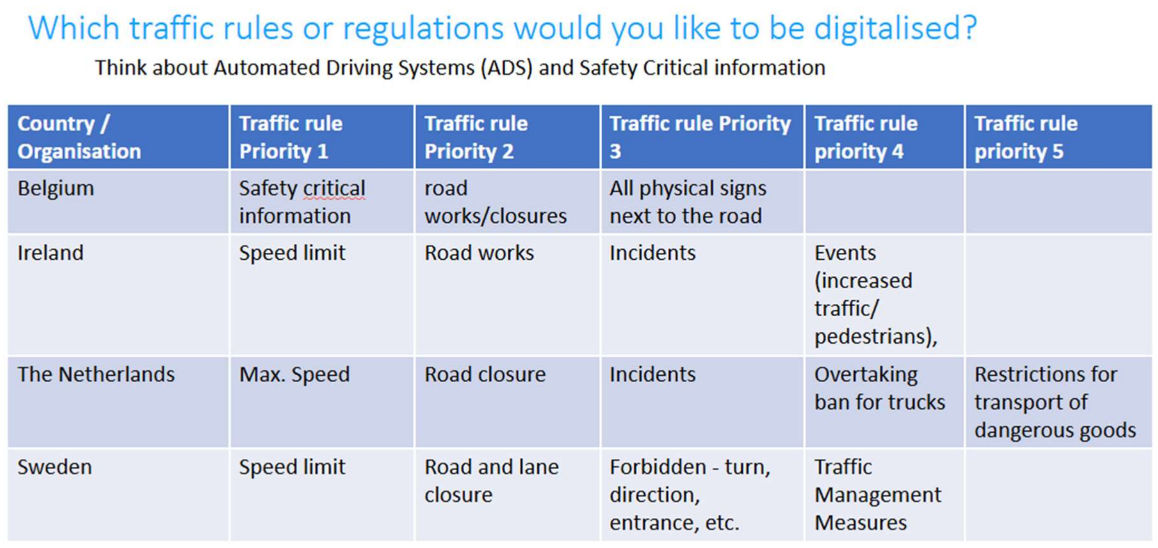
6 responses submitted

Which traffic rules from your perspective should be digitized?

"Actual maximum speeds, road works, everything you see trough your windscreen and is important for driving youy car"

"Special cases: traffic rules that are specific to a certain region/infrastructure/etcetera."

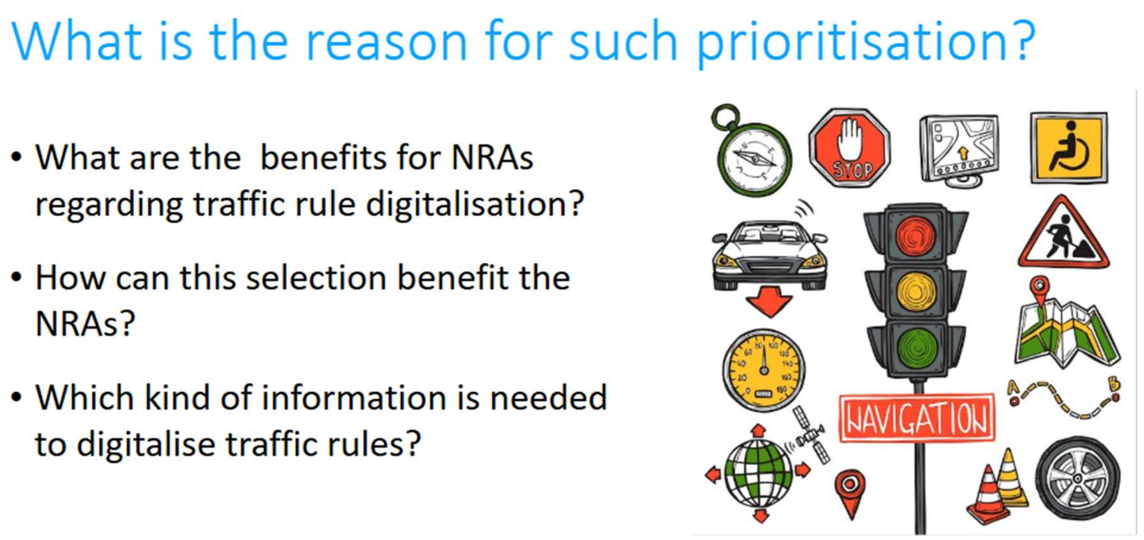
"Private all formal and informal rules"



Which traffic rules or regulations would you like to be digitalised?

Think about Automated Driving Systems (ADS) and Safety Critical information

Country / Organisation	Traffic rule Priority 1	Traffic rule Priority 2	Traffic rule Priority 3	Traffic rule priority 4	Traffic rule priority 5
Belgium	Safety critical information	road works/closures	All physical signs next to the road		
Ireland	Speed limit	Road works	Incidents	Events (increased traffic/ pedestrians),	
The Netherlands	Max. Speed	Road closure	Incidents	Overtaking ban for trucks	Restrictions for transport of dangerous goods
Sweden	Speed limit	Road and lane closure	Forbidden - turn, direction, entrance, etc.	Traffic Management Measures	



What is the reason for such prioritisation?

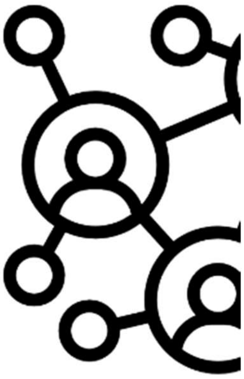
- What are the benefits for NRAs regarding traffic rule digitalisation?
- How can this selection benefit the NRAs?
- Which kind of information is needed to digitalise traffic rules?

Are you aware of any use cases or rule digitalisation initiative in your country or other countries?

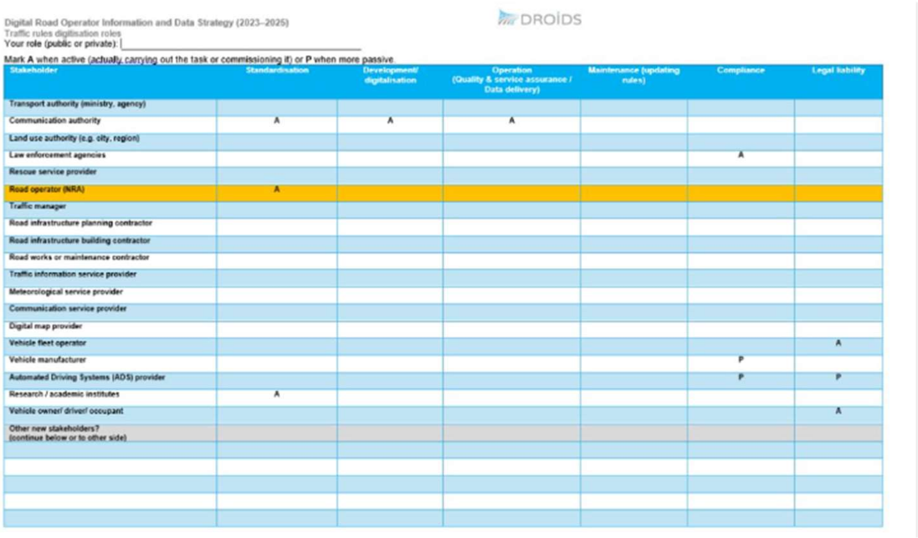
- What challenges do you see in context of traffic rules digitalisation?

NRA's role in traffic rule digitalisation

- How NRAs define their role towards digitalisation of traffic regulations?
- What are the internal / external (technological and organisational) challenges in digitalisation of traffic rules?



Traffic rule digitisation roles

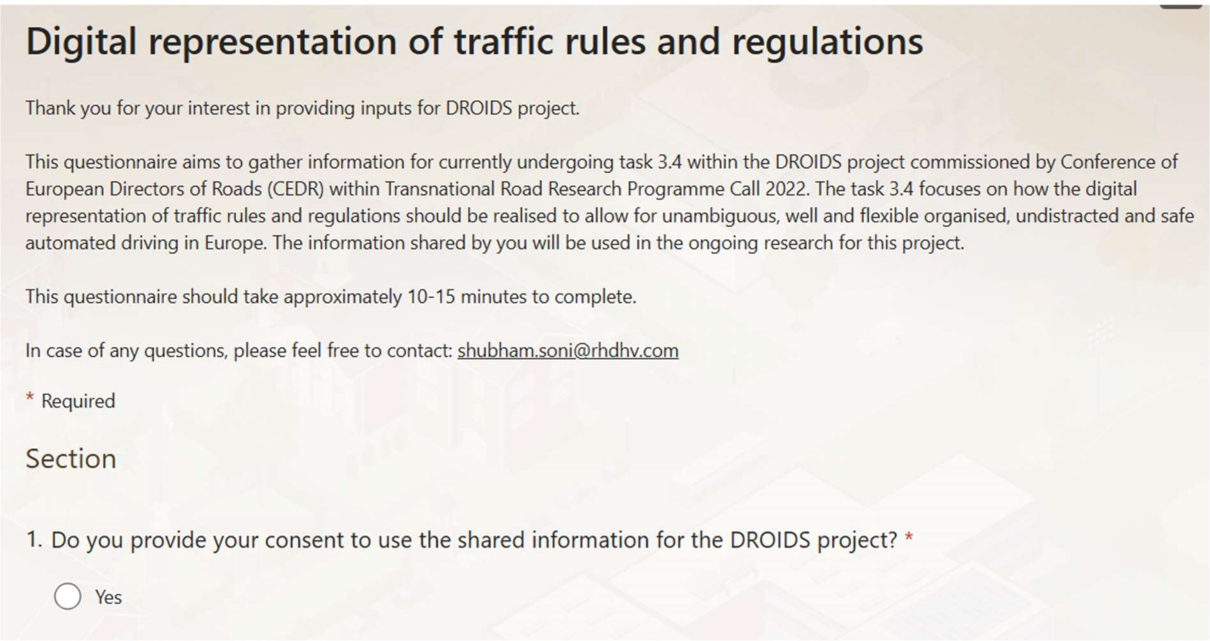


Digital Road Operator Information and Data Strategy (2023–2025)
Traffic rules digitisation roles
Your role (public or private): ______

Mark **A** when active (actually carrying out the task or commissioning it) or **P** when more passive.

Stakeholder	Standardisation	Development/ digitalisation	Operation (Quality & service assurance / Data delivery)	Maintenance (updating rules)	Compliance	Legal liability
Transport authority (ministry, agency)						
Communication authority	A	A	A			
Land use authority (e.g. city, region)						
Law enforcement agencies					A	
Rescue service provider						
Road operator (NRA)	A					
Traffic manager						
Road infrastructure planning contractor						
Road infrastructure building contractor						
Road works or maintenance contractor						
Traffic information service provider						
Meteorological service provider						
Communication service provider						
Digital map provider						
Vehicle fleet operator						A
Vehicle manufacturer					P	
Automated Driving Systems (ADS) provider					P	P
Research / academic institutes	A					
Vehicle owner/ driver/ occupant						A
Other new stakeholders? (continue below or to other side)						

Appendix B: Questionnaire



Digital representation of traffic rules and regulations

Thank you for your interest in providing inputs for DROIDS project.

This questionnaire aims to gather information for currently undergoing task 3.4 within the DROIDS project commissioned by Conference of European Directors of Roads (CEDR) within Transnational Road Research Programme Call 2022. The task 3.4 focuses on how the digital representation of traffic rules and regulations should be realised to allow for unambiguous, well and flexible organised, undistracted and safe automated driving in Europe. The information shared by you will be used in the ongoing research for this project.

This questionnaire should take approximately 10-15 minutes to complete.

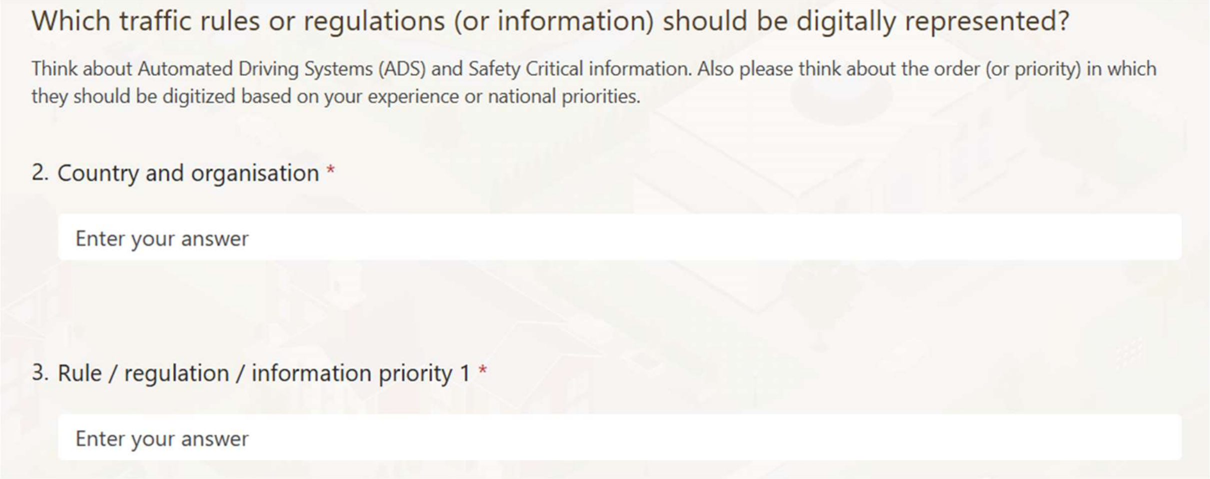
In case of any questions, please feel free to contact: shubham.soni@rhdhv.com

* Required

Section

1. Do you provide your consent to use the shared information for the DROIDS project? *

○ Yes



Which traffic rules or regulations (or information) should be digitally represented?

Think about Automated Driving Systems (ADS) and Safety Critical information. Also please think about the order (or priority) in which they should be digitized based on your experience or national priorities.

2. Country and organisation *

Enter your answer

3. Rule / regulation / information priority 1 *

Enter your answer

4. Rule / regulation / information priority 2 *

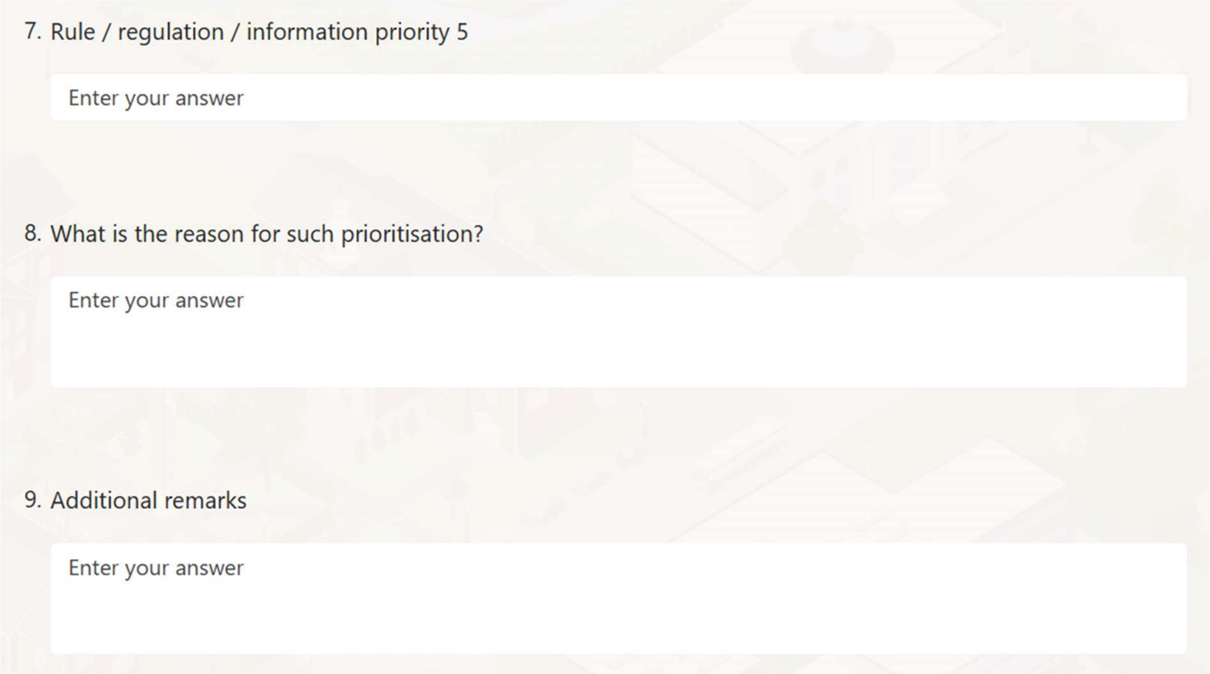
Enter your answer

5. Rule / regulation / information priority 3

Enter your answer

6. Rule / regulation / information priority 4

Enter your answer



7. Rule / regulation / information priority 5

Enter your answer

8. What is the reason for such prioritisation?

Enter your answer

9. Additional remarks

Enter your answer

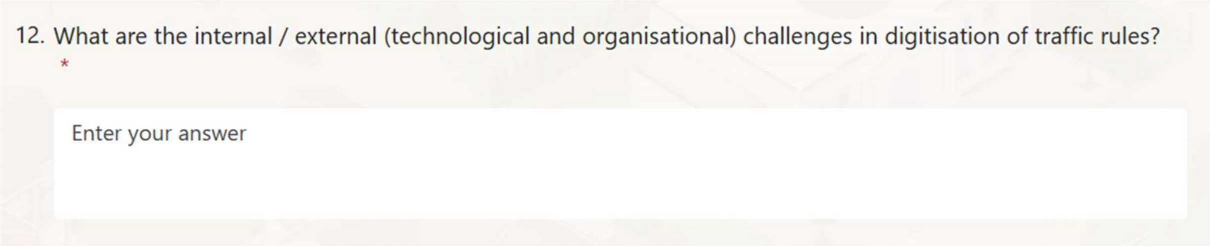
Benefits and challenges of digitisation

10. What benefits do you envision from traffic rule digitisation?

Enter your answer

11. What information / resources are needed by you to create/initiate development of digital representation of traffic rules and regulations?

Enter your answer



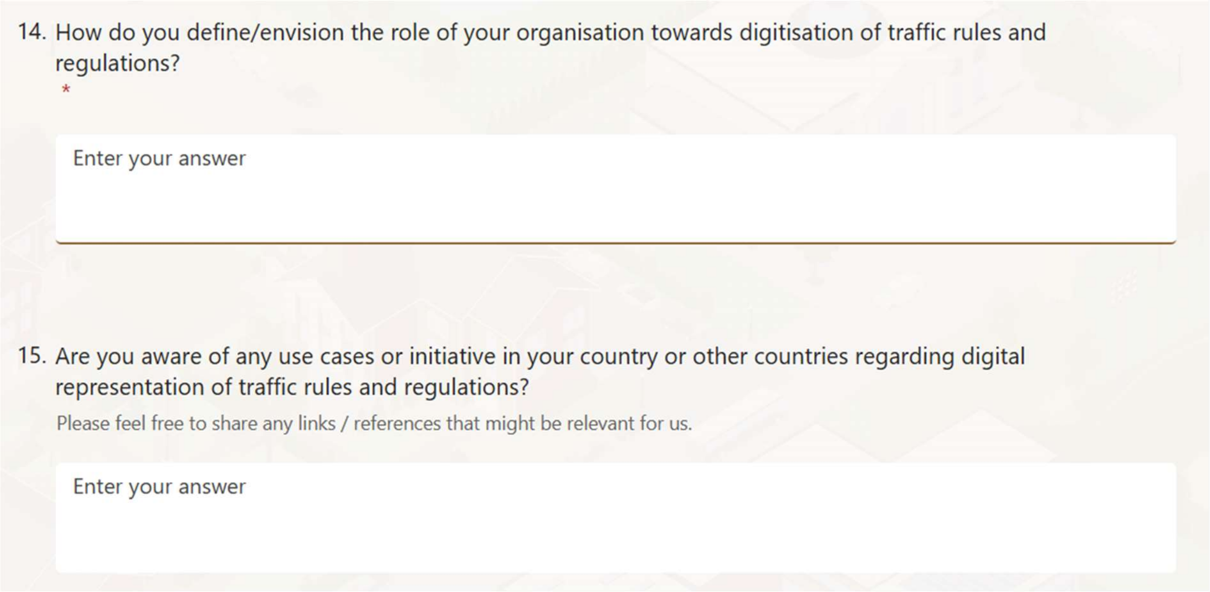
12. What are the internal / external (technological and organisational) challenges in digitisation of traffic rules? *

Enter your answer

Role of your organisation in digitisation of traffic rules and regulations

13. Which type of organisation do you belong to? *

- ○ Road operator (or NRA)
- ○ Transport authority (ministry, agency)
- ○ Data provider
- ○ Digital map provider
- ○ Vehicle manufacturer (or OEM)
- ○ Law enforcement agency
- ○ Land use authority (e.g., municipality, province, etc.)
- ○ Automated Driving Systems (ADS) provider
- ○ Research / academic institutes
- ○ Standardisation agency



14. How do you define/envision the role of your organisation towards digitisation of traffic rules and regulations? *

Enter your answer

15. Are you aware of any use cases or initiative in your country or other countries regarding digital representation of traffic rules and regulations?

Please feel free to share any links / references that might be relevant for us.

Enter your answer