Conférence Européenne des Directeurs des Routes
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Digital Road Operator Information and Data Strategy (DROIDS)

NRA roles in digital twins

Deliverables D2.2 Version 1.02

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Digital Road Operator Information and Data Strategy (DROIDS)

D2.2 NRA roles in digital twins

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Executive summary

The study objectives and expected end results included the role of NRAs in an ecosystem of digital twins for road infrastructure, information that NRAs should maintain and share for future use throughout the lifecycle of the road infrastructure

Methods of the study included literature survey, workshops, questionnaire and interviews. Also, collaboration with DROIDS work packages, especially Digital twin application evolution (WP3), and other CEDR Call 2022 Data projects of PRESORT and TIARA.

The conclusions of the research questions are summarised below.

(RQ1) What role the NRAs should take in the larger ecosystem of digital twins for road infrastructures, and how they should fulfil this role?

NRA or road operator roles (public and private) in the larger ecosystem of digital twins for road infrastructure were analysed and presented. Analysis included digital representation role tables in Annex 1 and role descriptions in Chapter 4 'NRA roles in digital twins' which included nineteen stakeholder roles in life cycle of road infrastructure digital representations. It was noted that the road operator role will evolve in collaboration with the ecosystem stakeholders depending on the use case and its requirements.

Analysis of the road operator roles indicated that road operators have an active role in many of the use cases life cycle stages. Natural active roles in digital representation full life cycle for road operators is in their core business of road maintenance and asset management as well as in use of the models in road planning and building. Use cases where private industry provides products and services, such as HD maps, signal control and probe vehicle data, road operator may have a more passive role, depending on the national implementation and business models with the industry.

(RQ2) What kind of digital representations (what kind of digital twins) should be maintained by NRAs? What will be the requirements for model-based AIM?

Road operator priorities for digital representations, "estimated likelihood of use case deployment by 2030 by at least three Member States" were presented. Road operators top three priorities were evaluated being asset management (digital model), speed limits of electronic/digital traffic rules/regulations (digital shadow) and road works (digital model). Digital models and digital shadows were estimated of being very likely for the use cases deployment by 2030 by at least three Member States. Following conclusions here summarised were made for road network operation use domains:

- *Planning and building:* During the planning and building phase, BIM digital representations are crucial as they represent various attributes of the built infrastructure.
- *Asset management and maintenance*: Asset information models (AIM) are relevant for the road operators during asset management phase.
- *Traffic management and information provision to external services digital representations* were concluded to be in early stage of development as the workshop, questionnaire and literature review results during the study provided only limited insight on the best practices. Nevertheless, it was concluded that since traffic managers and traffic management services by NRAs and road operators are developing common real-time operational picture together with the stakeholders and they have an active role and ownership with these digital representations

(RQ3) Will they need to extend the level of geometric and topological complexity for this data in order to prepare for model-based AIM and connected/automated driving?

The level of geometric and topological complexity from BIM and AIM models is usually sufficient for basic operations such as construction and maintenance of the infrastructure. However, for advanced applications such as creating a digital twin for connected/automated driving, the level of detail in such models is not sufficient. For applications in connected and automated driving, High-Definition (HD) maps offer more precise and accurate models.

The road operators must focus on standardising the information by adopting ISO 19650 and implementing an object type library from early phases of the project. By following standardised approach, the information stored in digital representations would be interoperable with variety of other applications.

Asset management use case digital model questionnaire result on life cycle of road infrastructure was provided. The results indicate an active role for road operator on full life cycle. Contractors and private industry have been evaluated of having an active role in maintenance and usage of the digital model.

(RQ4) How much responsibility should NRAs take for establishing and maintaining base data sets supporting automated driving such as High-Definition (HD) Maps, compared to the role of commercial Map Providers?

Many of the road operators core business and operational services already provide base datasets: these datasets are concluded below with specific attention to the HD maps.

Discussions with HD map providers indicated that it might be possible to make connections of HD maps with AIM/BIM systems given the quality of information is good, standardised and validated. Today, it is a bit early for road operators to take responsibility in managing the information for HD maps. The road operators should prioritise standardisation of their BIM process by implementing ISO 19650 and information by creating object type libraries. High maturity road operators who already have standardised OTL in place should pilot the usefulness of BIM and AIM information within HD maps in cooperation with HD map providers. At an early stage, road operators can focus on making sure that the information related to assets such as GIS information is organised, updated, and complete.

NRAs have not been developing high quality level HD maps, at least known to this study and not with the level of detail what the industry implements for automated driving systems requirements. It is questionable whether the HD maps would be NRAs core business especially when considering OEMs and service providers having vehicle fleets with substantial data collection capabilities to further enhance the HD maps and having a business case to use the map for example on automated driving.

HD maps use case digital shadow/model questionnaire results on life cycle of road infrastructure was provided. The results indicate an active role for road operator on full life cycle with possible ownership of the model map. Digital map providers, map data service providers and vehicle fleet operators were equally identified having an active role in full life cycle of the HD map use case. Also, traffic management and information provision to external services perspective to automated driving use cases data sources and information attributes in traffic management which were considered relevant and being often in road operator responsibility were presented.

(RQ5) What services and data is expected to be shared from NRAs?

Services and data that are typical and core business for NRA or road operator and their operational services and common operational picture should be shared with the ecosystem and are involved still with digital twins. These services and data can provide benefits for example on traffic safety and flow as well as reducing emissions. Important part of the benefits comes from OEMs and service providers who build their services by utilising the road operator data and services.

Depending on the ambition and available budget and capacity that NRAs have, additional services and data that may benefit new services outside of the current NRA's scope and responsibility could be expected to be shared. For instance, certain ODD attribute values that can augment CCAM services fall in that category.

There were also exceptions identified on services and data sharing. For example, data that has been bought from third-party service providers and data that is under ecosystem agreement, such as Data for Road Safety ecosystem, are outside of sharing scope. It need to be ensured that the data that is shared does not cause harm or damage. The damage can be for example security or privacy related issue. Target of the damage can be road user, public or private organisation, national authority or member state. Therefore, risk analysis is needed to evaluate any privacy, security or other risks that the data and services provided by the NRAs could include.

(RQ6) How do these different standards and specifications serve the future digital operator role of NRAs?

Standards provide services and data common technical solutions, interoperability, scalability and reduce cost risk, to mention few benefits, across European member states borders (Leiren Boag 2025). For example, sharing of safety related traffic information or electronic traffic rules for human and automated driving system-controlled vehicles requires collaboration between public and private partners. Standards ensure a common approach and safeguard joint digital representation implementations, i.e. future proof solutions and services. Several standards such as the following were referred in the study.

Building and planning

- ISO 19650 as the framework for information management and exchange throughout the project lifecycle
- IFC-5 and CEDR 2018 OTL
- BIM standard ISO 7817-1

Traffic Management standards and specifications were provided widely in the European regulation under the ITS Directive framework and its delegated acts, i.e. DATEX II, INSPIRE and TN-ITS. C-ITS standards have been as a basis in the C-Roads specifications. All of these serve the dynamic and static traffic management digital representations and twin in future development.

- ISO TC204 and CEN TC278 Intelligent Transport Systems
- DATEX II (EN 16157, CEN/TS 16157)
- INSPIRE specification
- TN-ITS (CEN/TS17268)
- C-Roads Platform European C-ITS specifications

(RQ10) How should the information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in maintenance of the physical infrastructure?

BIM information from design and construction phase can transition into asset information model which can be used by the road operators for asset management. However, to enable such integration, road operators must adopt common standards which will allow interoperability between different information systems.

To improve information management and exchange throughout the project's lifecycle, it is essential to adopt ISO 19650 as the framework. This standard provides a structured approach for managing crucial project data and ensures consistency across all stages.

Another important aspect is developing or refining existing Building Information Modeling (BIM) standards and guidelines, which will specify the requirements for data exchange, level of detail, and format compliance. Using formats like Industry Foundation Classes (IFC) and openBIM standards will facilitate seamless communication and integration.

Creating or using a comprehensive Object Type Library (OTL) is also vital. This library defines the properties and attributes of each asset type, ensuring consistency and interoperability across various projects and organizations.

Fostering active collaboration and communication between internal stakeholders, such as BIM and Asset Information Management (AIM) departments, is crucial for mutual understanding of requirements and capabilities. Additionally, engaging with external stakeholders, including contractors, design and engineering firms, consultants, and technology providers, helps identify information requirements and ensures the needs of all parties are met.

Road operators should also focus on data governance models to understand the responsibilities behind information management. The data governance is further discussed in DROIDS deliverable 5.2.

Road operator should also pay attention to the information that is a Key Performance Indicator for the service.

The following five guidelines for the road operators on how to collect, maintain and distribute the information in such a way that it is compatible with digital representations i.e. models, shadows and twins, were given in the study:

1. Identify road operator roles by use case
2. Utilise regulations and standards
3. Maintain trust
4. Exchange data with ecosystem stakeholders
5. Operate, evaluate and maintain

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DROIDS project description

DROIDS is a CEDR Transnational Road Research Programme Call 2022 project aiming to provide the 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 NRAs 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 National Road Authorities (NRAs) to digital road operators responsible for operating both the physical and digital road infrastructure. Some NRAs 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 NRAs 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 NRA core business and tasks is assessed in a thorough manner.

Thirdly, trust has been identified as the key attribute for NRA-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 CEDR Data Call 2022 PRESORT and TIARA projects).

Expected achievements and benefits to NRAs:

- DROIDS offers NRAs a clearer understanding of the prerequisites and roles associated with becoming a digital road operator, vital for NRAs considering this transition.
- It emphasizes the crucial step for NRAs: adapting processes to maximize benefits from digital tools.
- While DROIDS provides insights for process adaptation, the actual implementation must align with each NRA'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 NRAs in decision-making

Table of Contents

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List of Tables

List of Figures

1 Introduction

Road transport Digital Twin is defined by the DROIDS project as a realistic virtual representation of the real-world physical road transport systems. The road transport Digital Twin can include, depending on 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 deliverable's research questions are extracted from the DROIDS Work Packet 2 "NRA roles in digital twins" expected results as presented in Table 1. In other words, this deliverables results provide basis for the next phases and work packets of DROIDS, i.e., input for the further research and analysis. The decomposed research questions for this deliverable can be viewed in Table 2.

Table 1 The expected end result of DROIDS WP2.

DROIDS WP2 expected end result	WP2	Deliverables
ER1 An analysis of and guidelines for, the role of NRAs in an ecosystem of digital twins for road infrastructure, including:	X	D2.1 & D2.2 (this deliverable)
ER1.1 The state of the art	X	D2.1
ER1.2 What information should NRAs maintain and share for future use	X	This deliverable
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	X	This deliverable

Table 2 The research questions and the chapters where they are addressed in this deliverable.

DROIDS Deliverable 2.2 NRA roles in digital twins Research Question	Input from earlier DROIDS deliverables	Deliverable Chapter
(RQ1) What role the NRAs should take in the larger ecosystem of digital twins for road infrastructures, and how they should fulfil this role?	Input from the DROIDS Deliverable 2.1 State of the Art of digital twins for road infrastructure: - Tasks and responsibilities of road operators. - Actors related to digital twins - Benefits and challenges of digital twins for road operators	Chapter 4 Chapter 5
(RQ2) What kind of digital representations (what kind of digital twins) should be maintained by NRAs? What will be the requirements for model-based AIM?	Input from the D3.3 BIM representation for full life cycle of road infrastructure.	Chapter 4
(RQ3) Will they need to extend the level of geometric and topological complexity for this	Input from the D3.3 BIM representation for full life cycle of road infrastructure and D2.1 State	Chapter 5

data in order to prepare for model-based AIM and connected/automated driving?	of the Art of digital twins for road infrastructure.	
(RQ4) How much responsibility should NRAs take for establishing and maintaining base data sets supporting automated driving such as High-Definition (HD) Maps, compared to the role of commercial Map Providers?	Input from DROIDS deliverable D3.4 “Digital twin use cases – Digital transport regulations, opening new roads, automated lane level navigation”: data sets, such as required by High-Definition (HD) Maps, needed in digital twins.	Chapter 4 Chapter 5 Chapter 7
(RQ5) What services and data is expected to be shared from NRAs?	Services and data related to digital twins	Chapter 4 Chapter 5
(RQ6) How do these different standards and specifications serve the future digital operator role of NRAs?	Input from D3.2 Information maintenance and availability. Standards and specifications related to digital twins.	Chapter 4 Chapter 7
(RQ10) How should the information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in maintenance of the physical infrastructure?	Input from the D3.3 BIM representation for full life cycle of road infrastructure. Input from DROIDS Deliverable 2.1 State of the Art of digital twins for road infrastructure - What are the stages of road infrastructure life cycle and how can digital twin help to manage them - What stakeholders are involved in the life cycle	Chapter 6 Chapter 7

The study chapters are built around road operator digital representation use cases identified in the study. The methodology and used methods are presented in Chapter 2. The main chapters are summarised with in relevance to the use cases in order in the below Table 3.

Table 3 The study’s chapters content per digital representation use case.

Chapter	Use case relation	Content
3	Definition	Definitions of the digital representation use cases.
4	NRA role	National Road Authority or road operator role in the use cases.
5	Relevant information in NRA responsibility	Relevant information for NRAs to collect, maintain and share in a digital sense related to the use cases.
6	KPIs	Use cases related Key Performance Indicators (KPIs) for process improvement by digital twin.
7	Making the use cases information available	Best practices to make the digital twin use case related information available.

Finally, the Chapter 8 presents guidelines for the National Road Authorities and Chapter 9 Conclusions concludes the study results and next steps.

2 Methodology

The DROIDS project utilises the Digital Transformation Framework (DTF) structured approach that supports the design, development, planning and management of necessary organisational transitions. This Work Packet 2 and Work Packet 3 deliverables 2.1 and 3.1 is part of the first horizontal DTF Phase A that determines needs, requirements, and current practices.

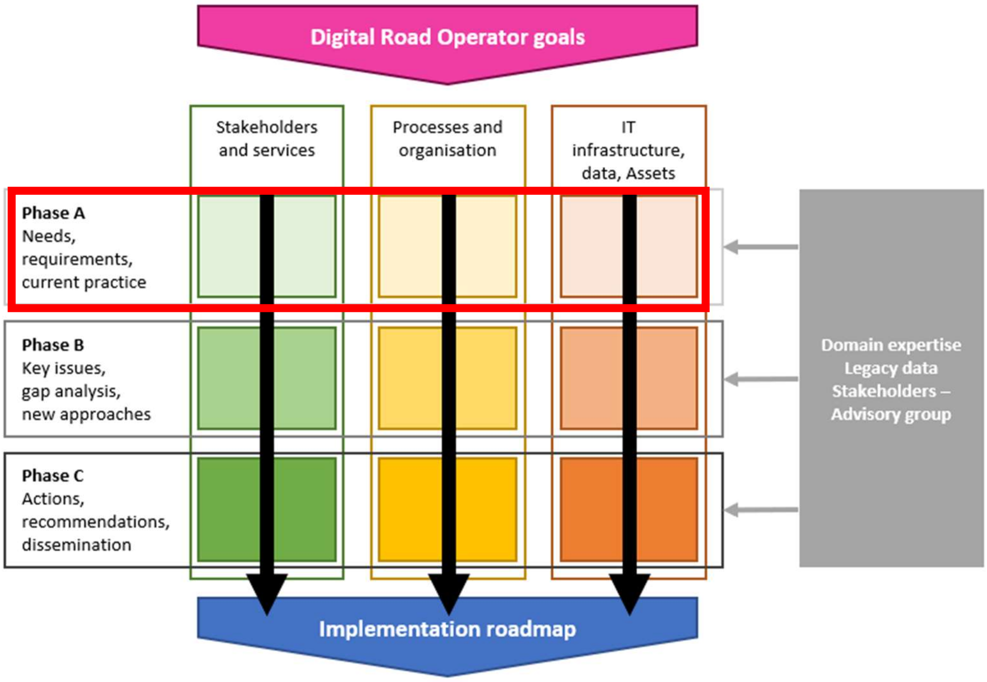

Figure 1 DROIDS project's Framework

The work utilised the results of the work carried out in analysing the state of the art of digital twins (Soni, et al. 2024).

As a starting point, the consortium created role tables for each digital representation use case found relevant for European road authorities. These tables were sent to the CEDR Data Call Programme Executive Board (PEB) as well as the CEDR Connectivity, Automation and Data Working group (CAD WG) for their comments.

Workshops

Next, the role tables were discussed in two workshops. The first one was hosted by the CEDR CAD WG in Vienna on 12 June also including CEDR Traffic management WG members. The second one was hosted by the CEDR Data Call PEB in Gent on 18 June. The two-event arrangement gave DROIDS access to the automated driving, traffic information and management expertise of the CAD WG as well as the planning, building and maintenance expertise of the PEB. In total, we had more than 20 CEDR experts participating in the two events.

In both cases, the workshop started by a general DROIDS presentation including the distinction between the different digital representations of the physical, digital and operational infrastructure of the road authorities and operators i.e. digital model, shadow and twin. This discussion also elaborated on the different use cases. The PEB workshop concluded in adding incident detection as a separate use case instead of including it under incident management. The naming of the different use cases was also improved on the basis of the discussions. For instance, the CAD WG workshop resulted in renaming surface condition monitoring as pavement surface condition monitoring. The digital representation use cases, discussed and commented in the workshop, are presented in the next chapter.

The workshops continued by looking at the roles of the various stakeholders in the life cycle of a digital representation from development to operation, maintenance and use. The CEDR experts had the possibility to change the markings proposed by the DROIDS consortium. Both the CEDR CAD WG members and PEB members proposed a number of changes in the role tables belonging to their specific expertise. The final versions of the tables are presented in Annex 1 of this report.

Interviews

The data were also collected via interviews carried out for the state-of-the-art work (Allmer 2024, Ihalainen 2023, Rossi & Kariniemi 2023, Timonen 2024) but mainly via the relevant literature.

Questionnaire

To gain further road operators experiences on digital twin implementations and best practices, a questionnaire was sent via email to them in early 2025. The questionnaire included two questions:

1. Has your NRA deployed a digital representation (model such as BIM/AIM, shadow, or twin) of the road infrastructure or part of it, including the physical road itself and/or its environment, roadside equipment, road users using the infrastructure, traffic rules on the infrastructure, etc.?
2. If you have such a digital representation deployment, can you share your experiences and best practices? For that purpose, can you please send short information of this experience and best practice elements as well as the contact details of the expert whom the project can contact for additional information?

Total of seven (N=7) road operator answers were received from Finland, Italy, Ireland, Iceland, Slovenia, Sweden and Switzerland. These answers were analysed mainly in the Chapter 7 Best practices in making digital twin information available.

3 Use cases of digital representation

This chapter presents a high-level introduction of digital representations use cases, i.e. situations where digital representations can be used by the road operator, as identified in the DROIDS project and validated by the road operators in a workshop as described in the Method chapter.

Digital representation refers to digital models, shadows or twins, depending on a use case and how it is applied. The DROIDS project definition states that road transport digital twin includes digital representation of elements such as road infrastructure, traffic with vehicles and pedestrians, road environment and land use. Additional background and other examples about different digital representation and digital twin use cases can be found from the previous DROIDS deliverable of digital twin state-of the-art (Soni et al. 2025).

Digital representation use cases and their allocation is shown in the below Table 4 in each use domain. The analysis in the following chapters 4–7 is carried out in the four different road network operation use domains of the digital representation presented in the below table:

- building and planning,
- asset management and maintenance,
- traffic management, and
- information provision to external services.

Table 4 The use domains related to each digital representation use case.

Digital representation use case	Road network operation use domain (subchapters in chapters 4-7)
Road planning and building	Road planning and building
Road maintenance	Asset management and maintenance
Winter maintenance	
Asset management	
Common operational picture for traffic management (network level use case)	Traffic Management
- Traffic jam conditions and end of queue	
- Surface condition monitoring	
- Tunnel closure and management	
- Road works	
- Safety related incidents and incident management	
- Incident detection	
- Event management	
Electronic/Digital traffic rules/regulations	
- General traffic regulations	
- Speed limits	
- Access Control / UVAR	
Signal control	
Hard shoulder running	
Automated traffic enforcement	Information provision to external services
HD Map	
Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness	

The use cases are connected and support each other throughout infrastructure and services lifecycle. For example, infrastructure life cycle of road planning and building, where a digital model is created, and which consists of PIM and BIM models to support the planning process. The road planning and building stage is also when the digital elements and future data exchange between the physical world and digital representation are planned. Decisions in the planning and building stage can have an impact on how the digital representation can be later in the life cycle of operation and maintenance used. For example, if a use case data exchange is done unidirectional or bidirectional, i.e., supporting digital shadow or digital twin real-time data exchange between the elements.

To mention few examples of connections between the use cases: digital representation of tunnel closure and management can benefit incident detection; road planning and building as well as asset management can link to road works digital representation; winter maintenance and surface condition relate to icy and snowy conditions and road friction.

Benefits of the use cases of digital representations, especially digital twins, are not yet fully known. In the DROIDS project results the interviewed road operator participants agreed that they are still in the early stages of implementing digital twins and do not yet have examples of how digital twins have significantly benefited their organizations" (Soni et al. 2025). Therefore, the below subchapters don't provide detailed list of benefits per use case, but instead a more common list has been provided below. The following list is not comprehensive but provides examples of estimated benefits, identified in the DROIDS project, of digital representations:

- Support of road infrastructure design and land use.
- Structural health monitoring and limitations evaluation, for example on bridges or help identify cracks and potholes in the pavement.
- Asset and condition monitoring throughout lifecycle.
- Real-time decision-making and responsive measures.
- Predictive maintenance information, for example to make timely decisions for the infrastructure maintenance.
- Simulation, for example infrastructure condition, traffic incidents and events.
- Training, for example operational traffic management personnel and collaboration between stakeholders, e.g. emergency services.
- Performance testing, for example tunnel ventilation systems.
- Reduction in volume of interventions and maintenance costs.

Road operator priorities for digital representations were questioned in a DROIDS project workshop where a DROIDS project members draft evaluation of priorities was presented. After the workshop, additional feedback was requested and received from the road operators. Road operators were questioned of "estimated likelihood of use case deployment by 2030 by at least three Member States." The results are presented in the below Table 5.

Table 5 Road operators estimated likelihood of use case deployment by 2030 by at least three Member

States. Results from the DROIDS project workshop and feedback of road operators.

Priority	**Use case**	**Estimated likelihood of use case deployment by 2030 by at least three Member States?**		
		Unlikely	**Likely**	**Very Likely**
	Common operational picture for traffic management (network level use case)			
	- Traffic jam conditions and end of queue	DT	DS	
	- Surface condition monitoring	DT		DS
9	- Tunnel closure and management	DT	DS	
3	- Road works	DT	DS	DM (static RW data)
9	- Safety related incidents and incident management	DT and DS (all stakeholders)		DM
4	- Incident detection	DT		DS
	- Event management	DT	DS (large events)	DM
8	Road maintenance	DT		DS
11	Winter maintenance	DT		DS
1	Asset management	DT	DS (high-risk assets)	DM
11	Road planning and building	DT (smart construction)	DS (smart construction)	DM
	Electronic/Digital traffic rules/regulations			
6	- General traffic regulations	DT	DS (dynamic)	DM
2	- Speed limits		DT (dynamic)	DS
4	- Access Control / UVAR		DT (dynamic)	DS
	Automated traffic enforcement		DS	DM
	Signal control		DT (dynamic)	DS
11	Hard shoulder running		DT	DS
11	HD Map	DT		DS
6	Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness		DT	DS

Each of the digital representation use cases presented in the previous tables in this chapter are described in more detail in the following subchapters. The aim is to define and provide basis of each use cases by presenting:

- Definition
- Objective
- Digital representation type of either digital model, shadow or twin, according to the road operators estimated likelihood of deployment of the use case by 2030 at least by three Member States, according to the DROIDS workshop results.

3.1 Road planning and building

Road planning and building refers to the road infrastructure life cycle stages of planning and building. The digital representation use case objective to road operator is to create a digital representation of the road infrastructure to support road network planning and building as a part of the road infrastructure life cycle management. Digital representation type very likely to be deployed by 2030 at least by three Member States road operators was a digital model.

3.2 Asset management and maintenance

Road maintenance refers to the maintenance life cycle of road infrastructure, for example maintenance of road pavement. The digital representation use case objective to road operator is to use digital representations on operational road maintenance by identifying maintenance needs and support maintenance actions.

Winter maintenance refers to the maintenance life cycle of road infrastructure that includes winter maintenance operations such as snow plowing or salting. The digital representation use case objective to road operator is to offer support for winter maintenance planning and operation by providing timely and accurate data to the digital representation about icy and snowy conditions on the road.

Asset management refers to managing of road infrastructure physical assets through its life cycle. The digital representation use case objective to road operator is to use digital representations on long-term strategic asset management, for example to support road network inventory and evaluate performance as well as costs and valuation.

3.3 Traffic Management

3.3.1 Common operational picture for traffic management (network level use case)

Traffic jam conditions and end of queue refers to a traffic condition with high volume of vehicles on a road causing congestion which can lead to slow speeds which further create queues of cars on the road. Traffic jam conditions can occur on one specific lane or on all lanes of a section of the road (C-Roads TF2), whereas the last vehicle or area of last vehicles in the traffic jam is the end of queue.

The digital representation use case objective to road operator is to use digital representations, which here requires information from the road, i.e. digital shadow, to locate where the traffic jam is occurring, and real-time data with end of queue information updates of the traffic to for example enhance road safety, and traffic management decision making to improve traffic flow.

Surface condition monitoring refers to a process of monitoring road surface, i.e. collecting and analysing data from road infrastructure or vehicle sensors. The digital representation use case objective to road operator is to use digital representations to locate and estimate surface condition and for example enhance road safety when communicating the surface condition to road users.

Tunnel closure and management refers to situations where a tunnel is closed for example due to safety reasons, which can be an accident, fire or collapse, i.e. situations were tunnel needs to be closed in timely manner.

The digital representation use case objective to road operator is to use digital representations to support management and decision-making of tunnel closures.

Road works refers to construction of a road, such as building or repairing. The digital representation use case objective to road operator is similar to road planning and building, i.e. digital representations on operational road maintenance by supporting maintenance actions.

Safety related incidents and incident management refers to incidents on the road network and traffic management as well as safety management of the incidents, for example in collaboration with emergency services. The digital representation use case objective to road operator is to use digital representations to support incident management.

Incident detection refers to a process of monitoring, identifying and analysing of incidents on a road network. The digital representation use case objective to road operator is to use digital representations to support incident detection on the road network.

Event management refers to a process of planning, coordination and executing traffic management strategies for example for large events such as concerts. The digital representation use case objective to road operator is to use digital representations to support event management process in the road network.

3.3.2 Electronic/Digital traffic rules/regulations

General traffic regulations refer to set of rules for how road users keep traffic safe and in good flow; these rules include for example traffic signals and signs. The digital representation use case objective to road operator is to use digital representations to support traffic regulation management and planning.

Speed limits refer to maximum and minimum speed by law on a road which is presented with a traffic sign. The digital representation use case objective to road operator is to use digital representations to support speed limit related action on a road network.

Access Control / UVAR refers to Urban Vehicle Access Regulations (UVAR) which regulates vehicular access to urban infrastructure The digital representation use case objective to road operator is to use digital representations to support the accessibility.

3.3.3 Signal control

Signal control refers to traffic signal control and its systems to real-time automation of lights to optimise traffic flow and safety. The digital representation use case objective to road operator is to use digital representations to support signal control process.

3.3.4 Hard shoulder running

Hard shoulder running (HSR) refers to dynamic use of hard shoulders as an extra driving lane with the aim to increase road capacity in times of high traffic demand (CEDR 2018). The digital representation use case objective to road operator is to use digital representations to support the use of HSR.

3.4 Information provision to external services

In the previous sections use case are described that are mainly related to existing NRA operational activities and responsibilities. There are also use cases that are not primarily the responsibility of a road operator and may not even be in the current NRA's scope, such as supporting CCAM services. **Automated traffic enforcement** refers to automatic roadside equipment such as cameras that help to reduce speeding, use of bus lanes, use of cell phone or seatbelt, noise, failure to yield, emission zones and running red lights or STOP signs, which are some of the most prevalent dangerous driving (DDOT). Vehicle communication also provides data and information of vehicle location and speed. The digital representation use case objective to the road operator is to use digital representations to support automated traffic enforcement related activities.

HD Map refers to highly accurate maps that represent the road environment with centimetre-level precision including lane-level semantic information, which can be used for example in automated driving and other road applications. The digital representation use case objective to the road operator is to use digital representations to support the creation of HD maps and further benefit from them.

Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness refers to a mechanism to facilitate and enable early deployment of Connected Automated Driving (CAD) by providing infrastructure support to the CAD system to aid its capability for Operational Design Domain (ODD) awareness. The digital representation use case objective to road operator is to use digital representations as a part of the DOVA support (Vreeswijk et al. 2023), which relates to Distributed ODD attribute Value Awareness

4 NRA roles in digital twins

The general roles of NRAs, i.e. national road authorities, vary from one European country to another. The NRA can have at least (one or more of) the following roles:

- road operator
- traffic manager
- (road) transport authority
- information service provider

All NRAs act as a road operator, and most also act as a traffic manager of the roads that they operate. The other two roles are not as frequently adopted by the NRAs. Nevertheless, all roles of the NRAs are covered in this chapter.

Despite its name, this chapter also covers all three types of digital representations, i.e. digital model, shadow and twin. The type of digital representation discussed, is clarified in the texts of the different subchapters. Typically, we look at the representations and roles that are general today and in the foreseeable future (around 2030).

The discussion covers the digital representations used for the NRAs' own processes as well as those used for other processes essential for facilitating the operation of the NRAs.

With regard to the life cycle of the digital representations, the discussion separates between four phases of the life cycle: development and deployment, operation, maintenance, and use. For all digital representation use cases, we identified the roles of all relevant stakeholders in the four phases of the life cycle as seen in Annex 1.

4.1 Building and planning

The road operators have a central role in the building and planning road infrastructure in all phases of its life cycle. The actual developer of the digital model (BIM) will likely be the planning or building or maintenance contractor, but the development will likely be carried on as a commitment from the road operator. In some countries, the development could be driven by a regulation given by the national transport authority. The land use authorities may also participate in the development of BIMs for instance related to other community infrastructure located in the road area.

The maintenance and updating of the BIM will likely also be carried out by the road operator or one of the above-mentioned contractors on its behalf containing the changes that these contractors have made to the physical infrastructure.

The actual operation of the BIM will be governed by the road operator ensuring that it will be used in accordance to the wishes of the road operator. In the actual building of the road, the building contractor will be the key operator of it and can naturally also update it during the building process in cases where the local conditions make such updates necessary.

It could be that in the future, automated driving systems or other novel road user types may need to add features to a BIM, but such are very difficult to predict. If this happens, their operators may also take over the responsibility of developing their own digital representations of the road infrastructure.

Many different stakeholders may use the digital models in addition to their developers, including transport and land use authorities, law enforcement offices, rescue operators, traffic managers, and research institutes.

4.2 Asset management and maintenance

Asset management

As the previous use case, the asset information models and shadows for the road infrastructure are hosted by the road operator. In the case of land use and other community infrastructure, the host can also be the local or regional land use authority. In the case of roadside weather stations, the host can also be a meteorological service provider.

All actors making changes in the assets such as building and maintenance contractors will be required to provide content updates to the digital representations. Content updates are also expected in the future from automated vehicles via their sensors detecting anomalies in the assets likely via their fleet operators or digital map providers.

Almost all other stakeholders use the asset management information in support of their own activities. This is especially important whenever the asset is damaged or not functioning as expected.

Road and winter maintenance

The road operator and traffic manager are the two actors responsible for the digital representations of the maintenance use cases but with different angles of approach. For the road operators, the digital shadow of maintenance status and operations is important for ensuring that the maintenance contractors are maintaining the road infrastructure according to their contracts so that the service level of the road network operations remains acceptable. For the traffic manager, the digital shadow of the maintenance is crucial in order to adapt the traffic management actions to the current and predicted status of the traffic and weather conditions. Furthermore, the maintenance of the traffic management systems is also crucial for traffic management.

It is also likely that advanced maintenance contractors and meteorological service providers host their own digital shadows or even twins to improve the efficiency of their operations in real time.

Automated driving systems and their fleet operators will provide updates to the digital shadows via in-vehicle sensor data

The data available from the digital shadows are used by almost all actors whenever the related data items are essential for the operation of the actor.

4.3 Traffic management

4.3.1 Common operational picture for traffic management

The first part describes the use cases for the common operational picture for traffic management on the network level.

Traffic jam conditions and end of queue

This digital representation use case is especially useful for traffic managers who are thereby aware of the location of the congestion in order to carry out measures to mitigate the problems as well as for traffic information providers who can provide the safety-relevant information to their customers. For these reasons both stakeholder types will likely develop digital shadows for this use case on the road networks with frequent congestion problems.

The data needed for locating the end of queue can be collected by fixed infrastructure sensors, but this requires considerable investments as sensors are needed for all lanes at least each 500m – 1km. Thereby fleet operators and automated driving systems play an important role in providing real-time floating vehicle data on traffic flow and thereby also on congestion and end of queues.

Pavement surface condition monitoring

Several different actors have now or in the near future their own digital shadows of the pavement surface condition status. The traffic manager needs it for performing road weather related traffic management, the maintenance contractors for carrying out winter and other road maintenance operations efficiently, the road operators for monitoring surface conditions against the maintenance contractors' performance targets, and the weather service providers for verifying their own forecasts. The traffic manager may acquire its data from one or several of the other existing digital shadows.

Today, the primary source of data is formed in most countries by a number of road weather stations located often at risky spots on the road networks. Road weather models implemented by private service providers that use atmospheric observations can further increase accuracy of the road weather and surface condition monitoring. In order to have a digital shadow covering the whole network requires floating vehicle data originating from automated or otherwise equipped vehicles and aggregated by a fleet operator or digital map provider.

Tunnel closure and management

The traffic manager is the primary host of the digital shadow of the tunnel closure and management system and its status. The road operator will likely have at least a digital model of the major tunnels in their network and this is used for maintenance planning and other purposes, where the traffic manager does not manage any tunnel control systems in the tunnel in question.

The road works and the maintenance contractor shall update the digital representation after having completed the maintenance actions. The details of the digital representation can also be updated by automated driving systems, fleet operators and digital map providers in cases of tunnel closures, openings and other irregular events.

Road works management

The digital representation use case relates primarily to the management of road works to maintain road safety and efficient traffic flow during the road works at the site. Many stakeholders will likely develop their own digital model or shadow of the road works.

The transport authorities may in the near future mandate the provision of digital shadows of the road works on highways, and the road operators will then include that in their contracts with the road works contractors including provision of real-time data on roadworks to the road operator and traffic manager. The road operators will likely set up their own digital shadows or models containing basic road works data related to the contracts for at least contract supervision purposes.

The road maintenance or building contractor will likely benefit from developing their own digital shadows of the road work based on their contracts. The key task of the contractors is to maintain the location and road work site's detailed driving lane description data in real time as they are the only stakeholder to actually hosting that data.

The traffic managers will likely also develop their own digital shadow of the road works and update it by the data received from the contractors, and provide warnings, possible detour and other information to the road users via their own channels and via service providers. The service providers can also maintain their own digital models or shadows of ongoing roadworks.

Digital map providers need to include at least the non-mobile roadworks in their maps. The same applies to future automated vehicle fleet operators, for whom the automated driving systems are an important source of road works data especially with regard to safe trajectories through the road works site.

There are multiple stakeholders using the information available in the digital representations of the road works.

Safety related incidents and incident management

Incidents are a key road transport issue on European road and street networks, and for this reason the European road authorities and operators have developed efficient processes and procedures to manage the incident situations so that the incidents will cleared as soon as possible. Traffic managers are thereby the traffic manager is the logical host for the digital shadow of the incidents to be managed. In many countries, the rescue service or police representative on location has the final decision-making power in managing the incidents, but typically the traffic control and guidance has been assigned to the traffic manager.

In some cases, the road operator may also host a digital representation of the incidents, but this could be restricted to specific types of incidents such as incidents involving hazardous goods or special transports, those related to national security, etc. It is also possible that vehicle fleet operators such as public transport operators maintain their own digital shadows concerning incidents affecting their services.

Multiple actors may provide data updates to the digital representations. Such actors include the rescue, police, maintenance contractor representatives attending the incident site, traffic information, meteorological service, and digital map providers as well as automated driving systems and road users. Almost all stakeholders are users of incident information.

Incident detection

Several above-mentioned data items are real-time and safety-related traffic information that are generated via roadside equipment or probe vehicle data, including smart phone applications. The data can be produced by several stakeholders, for example either by the road operator, service providers or vehicle manufacturer.

The road operator can take part in the incident detection by using its own sensors, such as cameras or radar, but also procure probe vehicle data. *The traffic manager* on the other hand has an active role on detecting road events such as incidents.

Traffic information service providers and *vehicle fleet operators* can provide incident detection through probe vehicle and crowdsourced smart phone application data. The first mentioned can use vehicle sensors such as hazard lights, acceleration or radar sensors when detecting incidents.

Rescue service providers can provide emergency call data, eCall service data, or even emergency vehicles provided data about incidents on the road. *Law enforcement* members and vehicles may provide incident data as well. Data privacy considerations and regulation has to be taken account and may limit the provided data.

Event management

Major event attracting large numbers of participants often cause problems on the road networks, typically especially at the end of events when most participants leave the event site at the same time. The traffic managers should host at least a digital model of the major events affecting their road network, but also the road operators may do so.

The key data provider is the event organiser, who might even have an own digital shadow of the events organised.

Concerning the data updates and digital representation use, the use case is very similar to event management.

4.3.2 Electronic/Digital traffic rules/regulations

General traffic regulations

As the use case deals with general traffic law, statutes and other regulation applying generally in the state or nation, the logical host of a digital model or shadow would be the transport authority responsible for the preparation of such regulations. The law enforcement authorities, road operators, traffic managers, digital map providers, vehicle fleet operators, vehicle manufacturers, and automated driving system developers should participate in the development phase to ensure that the digital representation developed will cater to the user needs.

As the fixed and temporary regulatory road and traffic signs need to be also included in the digital representation, the land use authorities, law enforcement authorities, road operators, traffic managers, digital map providers, vehicle fleet operators, vehicle manufacturers, and automated driving system developers may provide updates to the digital representation depending on the national agreements.

The automated driving systems will likely maintain their own digital shadow of traffic regulations containing additional regulations concerning their specific ODD and transfer of vehicle control regulations. This could also be under the responsibility of the ADS' fleet operator.

Speed limits

Typically, the road operator is responsible for the fixed speed limits and the traffic manager for dynamic, variable speed limits. They are thereby also the natural hosts for the digital shadow of their speed limits capable of providing real-time speed limit information to road users as required by the ITS Directive. Nationally, the road operators and traffic managers can naturally agree on the actual host. In such a case, the traffic manager could be the obvious solution as the dynamic speed limits are the primary challenge in maintaining the digital shadow.

Several other actors have an impact on the speed limit values and may provide updates to the digital representations depending on national and/or regional practices. Such include the land use authority (urban areas especially), law enforcement officials, rescue service providers. road building and maintenance contractors. Digital map providers, automated driving systems and their fleet operators as well as vehicle drivers and occupants can detect errors in the digital shadow on the basis of their own observations and thereby propose changes in the digital shadow.

Access Control / UVAR

The host of the digital shadow will depend on the use case. In the case of road tolls, it is the road operator whereas in the case of access control it would likely be the traffic manager. For urban vehicle access regulations and area-wise road user charging, the host is likely the city as the land use authority. The transport authorities may have a key role in regulating the various use cases.

The views of the digital map providers, vehicle manufacturers and fleet operators should be addressed when developing the digital representations.

4.3.3 Signal control and hard shoulder running

Signal control

The digital representation of signal control will be hosted by the traffic manager. The rescue operators and road operators may be involved in the development of the use case if the access of e.g. the fire engines or road clearance vehicles need to be controlled via traffic signals. Road works and maintenance contractors may update the digital representation in case they operate traffic signals at their work sites.

In many cases, where all traffic signals are operated utilising the digital representation also as a user interface, the digital representation is actually a digital twin where any change in the digital twin is immediately deployed in the signals themselves.

Hard shoulder running

The digital twin of hard shoulder running will be hosted by the traffic manager. As the use of hard shoulder running has a major impact on road throughput as well as the use of the hard shoulder to other uses such as emergencies, the road operator may be closely linked to the development and operation of the use case.

The road works and maintenance contractors as well as rescue service operators will likely affect the use case due to their own activities on the related road sections.

As noted above, the logical digital representation in this use case is the digital twin.

4.3.4 Summary of traffic management related data items

The key stakeholder in traffic management is, naturally, the traffic manager. The roles of other stakeholders are closely linked to the use case. In many cases, the automated driving systems, vehicle occupants and fleet operators observing the road environment detect anomalies between the digital representations and their own observations which should be used in updating the contents of the digital representations to match the factual conditions.

The digital representations vary from digital model to digital twin so that the digital shadow is the typical representation in the traffic management use cases. In dynamic traffic management operated at traffic management centres, the digital twin is a useful assisting tool.

4.4 Information provision to external services

Automated traffic enforcement

In the automated traffic enforcement, the law enforcement authority is the natural host of the digital shadow. Depending on national agreements, the road authorities and traffic managers may also act as the hosts in cooperation with the law enforcement agencies. The land use authorities may participate in the use in the case of e.g. the enforcement of compliance to urban vehicle access regulations. But several other authorities and departments have a say in various use cases that are related to restricted use or access of parts of the road network. For example, regarding Urban Vehicle Access Regulations (UVAR), various motivations exist related to (re)distributing scarce public assets and minimizing the negative impacts of traffic (emissions, noise, etc). Therefore, policy departments and the units responsible for planning and design of public space, housing, logistics, healthcare and environmental issues are involved. Other examples in addition to UVAR are flexible use of dedicated infrastructure such as bus lanes or hard shoulders by specific categories of vehicles (e.g. taxis, electric vehicles, etc.). Also parking, loading and unloading fall in this category as enforcement is essential.

HD Map

Land use authorities and road operators typically host digital map models of their infrastructures as basic foundations of their own core business. The digital shadow type of HD maps are hosted by commercial digital map providers responsible for the development, operation and maintenance of the digital maps.

The automated driving systems and fleet operators may provide update proposals for the digital shadow contents in the case of anomalies detected. This would benefit both the fleet operators as well as the HD map providers. The vehicle fleet operators likely also operate their own digital shadows building on top of HD maps but containing ODD-related geofences and other additional attributes relevant to their fleet.

Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness (DOVA)

As the automated driving systems can operate safely only within their Operational Design Domain (ODD), they need to be always aware of the status of each ODD attribute in their location and their possible position at least during the next 10 seconds (Ko et al. 2024). The solution proposed to accomplish this is to use the Distributed ODD attribute Value Awareness or DOVA concept, developed by CEDR project TM4CAD (Khastgir et al. 2023).

As only the Automated Driving System (ADS) developer and the ADS fleet operator know the full properties of the ODD, the fleet operator would be the logical host of the digital shadow for DOVA. The contents of the digital shadow could benefit from updates from the road operator, traffic manager, law enforcement, rescue services, road contractors, meteorological and traffic information service providers, communication infrastructure providers, digital map providers and individual ADS. These data updates are mostly made available from the digital representations described earlier in this chapter.

5 Relevant information in NRA responsibility

This chapter introduces relevant information for NRAs to collect, maintain and share in a digital sense. The following key NRA processes were analysed: planning, building, asset management, maintenance, and traffic management as well as processes of other stakeholders supported by NRAs such as rescue, police, CCAM, other fleet operators and service providers.

The analysis per relevant information in the subchapter includes the following content. It should be noted that level of detail describing the information needed might vary according to service and process:

- Use case name
- Means of data provision, e.g. infrastructure, probe vehicle data, etc.
- The key types of information, e.g. location and type (attributes) with possible examples, with scope in NRA responsibility.

Examples of the application of the information with state-of-the-art digital twins used by road operators in the main domains of road infrastructure building, asset management, traffic management and partly external services, are given in the DROIDS similarity named report by Soni et al. (2025).

5.1 Building and planning

Road operators across Europe are increasingly adopting BIM to enhance project delivery, improve collaboration, and optimize asset management. As discussed in deliverable D3.3: BIM representation for full lifecycle of road infrastructure (Soni, 2024), the implementation of BIM for digital representations varies between different NRAs. 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.

As described in section 4.1, the road operators have a central role in the building and planning road infrastructure in all phases of its life cycle. It involves the development, maintenance and updating the digital representations during the design and construction either by themselves or through an contractor on their behalf.

The following few information are instrumental for the road operators to collect, maintain and share in a digital sense.

5.1.1 Object type libraries (OTL)

An OTL is a standardized information model that defines and organizes object types in a structured manner. These object types can represent various infrastructural elements such as bridges, roads, tunnels, streetlights etc. and contains information about their characteristics such as maintenance date, contractor, location etc.

An OTL acts as a common language, ensuring everyone involved understands the meaning and relationships between information. Just like dictionaries for natural languages, an Object Type Library provides a common framework for improving communication between different parties and their software systems (Rikkert, 2023, 2024, OTL Publicatieomgeving, n.d.).

In order to standardise the information within the digital representations, prevent misunderstandings and misinterpretations, improves interoperability and enable seamless data exchange between different businesses and applications, road operators could build, manage and share the OTL. Many road operators already have OTL which are accessible to the masses. A few examples are:

- The Netherlands – Rijkswaterstaat (RWS) - https://otl.rws.nl/
- Belgium (Flanders) - Agentschap Wegen en Verkeer (AWV) - https://wegenenverkeer.data.vlaanderen.be/
- Germany – Federal Ministry of Transport and Digital Infrastructure (BMDV) - https://www.okstra.de/
- Finland - buildingSMART Data Dictionary (BsDD) - https://search.bsdd.buildingsmart.org/uri/FTIA

5.1.2 Digital representations

BIM is fundamentally centered around the creation and management of digital representations, often called models. These models form the core of the BIM process, offering a comprehensive digital depiction of a physical asset. A crucial aspect of the BIM workflow is the creation and management of these digital representations or models of the asset.

The most common type of digital representation is geometric models, which provide detailed 2D or 3D depictions of the infrastructure. These models convey information about the size, shape, and spatial relationships of various components in the infrastructure and thus can be a valuable source of information in the later stages of asset's lifecycle such as asset management. However, BIM models go beyond mere visual representations; they also encompass rich information about infrastructural elements such as materials, maintenance, costs, and performance (Soni S., 2024).

The creation and maintenance of digital representations during the design and construction phase of the asset in accordance with information standards such as OTL and process standards such as ISO 19650 can be ensured by the road operators. The road operators should aim to achieve a higher level of BIM technology maturity levels aiming towards standards for interoperability and efficient data management.

With the help of standardized data formats and classification systems, BIM information reuse ensures that valuable information generated during the design and construction phases can be effectively utilized for other purposes such as asset management or creating digital twin of road infrastructure for operation or maintenance of the project. This approach not only enhances collaboration among stakeholders but also improves data accuracy, reduces redundancy, and supports sustainable asset management practices. The digital representations can contain information such as:

1. Geometric Data:
    - 3D Terrain Models: Accurate representation of the existing ground surface.
    - Road Alignment: Precise horizontal and vertical geometry of the roadway.
    - Road Components: Detailed models of road layers (pavement, sub-base, etc.), sidewalks, curbs, and medians.
    - Structures: 3D models of bridges, tunnels, overpasses, and underpasses.
    - Intersections and Roundabouts: Accurate representation of complex junction designs.

2. Non-Geometric Data (Information)
    - Material Properties: Specifications of materials used in construction (e.g., concrete strength, asphalt type).

- Construction Sequencing: Scheduling information, including construction phases and timelines.
- Cost Estimation: Data for quantity takeoffs, cost calculations, and budget management.
- Utilities: Location and specifications of underground and above-ground utilities (e.g., water pipes, electrical cables).
- Geotechnical Data: Soil properties, stability analysis, and geological information.
- Environmental Data: Information on environmental impact assessments, drainage patterns, and ecological considerations.
- Safety Information: Data related to traffic safety, signage, and barriers.
- Legal and Regulatory Information: Information regarding land ownership, permits, and regulations.

5.2 Asset management and maintenance

Various interviewed road operators in Task 3.3 of DROIDS have mentioned that there are various components within their BIM digital representations that can be effectively reused for asset management and the development of Digital Twins. Standardizing processes and data are crucial for the seamless migration of information from building and planning phase to asset management and operations.

As asset management and maintenance is one of the core responsibilities of the road operators, which can be effectively managed by an Asset Information Model (AIM). An AIM is a model that compiles the data and information necessary to support asset management, that is, it provides all the data and information related to or required for the operation of an asset (Asset Information Model AIM, 2022).

An AIM can provide graphical and non-graphical data and information as well as documents and metadata. It can relate to a single asset or to a portfolio of assets. An AIM can be created from existing asset information systems, from new information, or from information in a Project Information Model (PIM) that was created for the construction of a new asset.

An AIM may contain the following information:

Asset Identification:

- Unique identifiers for each asset (e.g., road segments, bridges, signs).
- Location data (GPS coordinates, linear referencing e.g., hectometer).
- Asset classification and hierarchy.

Asset Characteristics:

- Material properties (e.g., pavement type, concrete strength).
- Dimensions and specifications.
- Installation dates and construction details.
- Manufacturer information.

Condition Data:

- Inspection records and reports.
- Condition ratings and indices (e.g., pavement condition index).
- Defect tracking and analysis.
- Deterioration models and predictions.

Maintenance Data:

- Maintenance history (repairs, replacements, inspections).
- Maintenance schedules and plans.
- Maintenance costs.
- Work orders and records.

Performance Data:

- Safety records and incident data.
- Environmental monitoring data.
- Performance indicators (e.g., ride quality).

Lifecycle Data:

- Expected lifespan and service life.
- Replacement and rehabilitation plans.
- Decommissioning plans.

Associated Documentation:

- As-built drawings and specifications.
- Maintenance manuals.
- Warranty information.
- Legal and regulatory documents.

An up to date AIM represents digital model of the road infrastructure where digital entities closely represent physical entities. For effective management of assets, it is instrumental for road operators to keep AIM updated. Since majority of maintenance is potentially carried out by contractors, it is instrumental to have well defined standards for information and process to ensure the models remain useful and relevant.

5.3 Traffic management

This chapter lists key traffic management related data items and example data properties that are in road operator responsibility and can be used in digital models, shadows or twins. The analysis is based on the selected digital representation use cases introduced in the earlier chapter of Use cases.

5.3.1 Common operational picture for traffic management

The first part lists common operational picture for traffic management (network level use case) use cases data items.

Traffic jam conditions and end of queue

The traffic jam conditions and end of queue refers to a traffic condition with high volume of vehicles on a road causing congestion which can lead to slow speeds which further create queues of cars on the road. The following means of data provision have been identified as a source of traffic jam conditions and end of queue:

- Probe Vehicle Data (PVD) from OEMs, service providers and vehicle fleets.
- Mobile network aggregated mobility data
- Roadside units, sensors and Intelligent Transport Systems, e.g. induction loops, traffic signals, cameras and V2I communication.
- Crowdsourced data which includes traffic flow data.

The key types of information attributes in traffic jam conditions and end of queue for the NRAs are (adapted from Hall 1992):

- Traffic speed (distance per unit time)
- Traffic flow (vehicles per unit time)
- Travel time over known length of road
- Occupancy (percent of time a point on the road is occupied by vehicles)
- Traffic density (vehicles per unity distance)
- Location of the traffic jam and end of queue with coordinates
- Queue length
- Duration of the traffic jam

NRA responsibility often covers infrastructure data, such as induction loop detectors and camera systems as well as roadside units such as V2I communication. Probe vehicle data is mainly available (for purchase) from the OEMs and service providers, but in some cases also NRA vehicles or vehicle fleets such as from contractors may be available to provide probe data. Traffic jam calculation can involve several attributes and data sources, the final calculation being a part of a data fusion to provide accurate results, especially when estimating end of queue.

Surface condition monitoring

Surface condition monitoring refers to a process of monitoring road surface, i.e. collecting and analysing data from road infrastructure or vehicle sensors. The following means of data provision have been identified as a source of surface condition monitoring:

- Probe Vehicle Data (PVD) from OEMs, service providers and vehicle fleets, e.g. road friction
- Roadside units, sensors and Intelligent Transport Systems, e.g. road weather stations
- Weather radar & satellite (Vaisala 2020)
- Crowdsourced data of road surface conditions and weather observations. (Vaisala 2020)

The key types of information attributes in surface condition monitoring for the NRAs are:

- Friction level
- Road and air temperature
- Humidity
- Location
- Road class and location of bridges (Vaisala 2020)
- Road maintenance activities (e.g., de-icing, plowing) (Vaisala 2020)

NRAs can have road infrastructure and roadside units such as road weather stations to gather surface condition information; this information need to be shared openly among road users. Road weather and surface condition is available for purchase from private industry, which often is a combination of weather models and probe vehicle data. In addition, NRAs might have their own vehicles or contractor data on surface conditions available, for example through winter maintenance.

Tunnel closure and management

Tunnel closure and management refers to situations where a tunnel is closed for example due to safety reasons. The following means of data provision have been identified as a source of tunnel closure and management:

- Intelligent Transport Systems, roadside units and sensors, e.g. Tunnel Management System.
- Tunnel CCTV cameras with real-time stream monitoring and incident as well as vehicle breakdown detection capabilities.
- Manual phone calls from emergency phones or mobile phones to emergency or traffic centres reporting incidents.
- Probe Vehicle Data (PVD) from OEMs, service providers and vehicle fleets, e.g. road friction

The key types of information attributes in tunnel closure and management for the NRAs are (adapted from Jung et al. 2022):

- Air quality and level of individual gases, e.g. oxygen and carbon dioxide which can be used also for fire and smoke detection as well.
- Air pressure
- Visibility
- Airflow rate and tunnel ventilation fan status
- Temperature and humidity
- Vehicle speeds, count, flow, etc.
- Weather data, e.g. rain and wind.

Tunnel management systems in responsibility of the NRAs with sensors and cameras provide most of the information. Probe vehicle data can still provide additional information about the tunnel conditions and events. Similarly emergency centre information for example on incidents can be combined with the management system information.

Weather data is also important, although a tunnel inside is protected from rain or snow, the tunnel entrance section, or access zone, can be prone to accidents depending on tunnel height and topographic features which for example causes shadiness, slipperiness or poor visibility (Jung et al. 2022).

Road works

Road works refers to construction of a road, such as building or repairing. The road works use case includes following means of data provision as a source:

- Reported road works information saved in the NRA database
- Road work trailer with Truck-Mounted Attenuator (TMA) that includes ITS and/or C-ITS hybrid communication road-side unit (short- and long-range communication)
- Road work or maintenance vehicles with OBU providing real-time data
- Smart phone applications that can be stakeholder specific (e.g. contractor) or provide crowdsourced data

The key types of information attributes in road works for the NRAs are:

- type of road work, e.g. repair, installation, resurfacing
- location of road work along road and carriageway with possible direction of impact
- lane or lanes impacted
- validity time of the road work, for example weekdays and time of day

Road works information described above has a high value for the customers, both road users and traffic information services providers benefit from the information. Timely updates of road works information will provide value for the digital shadow.

Static road works information, especially long-term road works, are reported and saved directly in the NRA or traffic manager databases by contractors, depending on the agreements and national differences. Dynamic road works information from road work trailers and maintenance vehicles provides real-time updates of the location of the road works or road works vehicles.

The digital shadow consists of the digital model of the road work site and real-time data. The digital model can include the road work site geometric information of the road work site. The real-time data can include updates on the road work site road geometry, road environment, road works warning information and maintenance vehicles location as well as traffic information. The road operator may monitor real-time updates of the road work site and simulate different traffic scenarios to support decision-making.

Safety related incidents and incident management

Safety related incidents and incident management refers to incidents on the road network and traffic management as well as safety management of the incidents, for example in collaboration with emergency services. The following means of data provision have been identified as a source of safety related incidents and incident management:

- Rescue and emergency services data on incidents and incident management, for example incident recovery events such as crash scenes, crime scenes, dropped loads, landslides, avalanches, etc. (Khastgir et al. 2023)
- Roadside cameras with real-time monitoring
- Roadside units and ITS
- Probe Vehicle Data on incidents, such as hazard lights or other vehicle sensor data.
- Crowdsourced data such as from smart phone applications that can provide incident data.
- Manual phone calls from emergency phones or mobile phones to emergency or traffic centres reporting incidents.

The key types of information attributes in safety related incidents and incidents management for the NRAs are:

- Location of the incident
- Type of incident (accident / people on road / animal on road / obstacle on road / broken vehicle / vehicle on fire / slow convoy etc.)
- Whether the incident is already being managed on site or not
- Severity of the incident
- Predicted duration of incident (time to incident clearance) if available
- Affected area, roads, lane or lanes totally or partly blocked due to incident or incident management of the emergency services

Safety related incidents and incident management are one of the key tasks for NRAs. All incident related data should be shared openly by the NRAs. Several sources and attributes of information can be found, many of them from private industry such as probe vehicle data and used together to formulate reliable and accurate information of incidents.

Incident detection

The incident detection use case refers to detection of traffic incidents and it includes collection of incident related traffic data. The following means of data provision have been identified as a source of incident detection:

- Rescue and emergency services data on incidents, for example incident recovery events such as crash scenes, crime scenes, dropped loads, landslides, avalanches, etc. (Khastgir et al. 2023)
- Roadside cameras with real-time monitoring and incident detection capabilities.
- Roadside units with V2I communication
- Probe Vehicle Data on incidents, such as hazard lights or other vehicle sensor data.
- Smart phone applications that can be stakeholder specific (e.g. contractor) or provide crowdsourced data
- Manual phone calls from emergency phones or mobile phones to emergency or traffic centres reporting incidents.

The key types of information attributes in incident detection for the NRAs are:

- location of incident along road and carriageway (which direction is mostly affected)
- lane or lanes totally or partly blocked
- type of incident (accident / people on road / animal on road / obstacle on road / broken vehicle / vehicle on fire / slow convoy etc.)
- whether the incident is already being managed on site or not
- predicted duration of incident (time to incident clearance) if available
- recommended detour(s) to bypass the incident site

Any items listed above should be made available to the public directly via variable message signs or indirectly via traffic information providers. For the latter, incident related information is one of the most important data items in great demand by their customers, and for them a digital shadow of incidents detected could be an optimal solution to provide real-time data on the development of at least the major incidents. Some incidents are very minor in terms of duration and impact (parking temporarily on the motorway shoulder, or a deer crossing the road) so there is not a viable business case for producing a digital shadow for those.

The data is typically provided by the traffic manager, which can be the role of the NRA. The road operator naturally benefits also from the incident detection due to improved road network operation due to quickly detected incidents and thereby timely incident management.

Event management

The event management use case provides a digital representation of the measures to mitigate the impact of major public events and the increased traffic volumes caused by the participants in these events. The use case may include the following data items:

- event type (sport, congress, carnival, convoy, etc.) and identification (e.g. name of event)
- location of event
- exact timing of the event and the expected times of exceptional congestion in various locations
- parts of road network particularly affected by the event and the event-related dynamic traffic restrictions
- temporary transport service changes due to event (additional parking facilities, altered public transport services, altered emergency vehicle routes, etc.) if any

- traffic management plan for the event including the signing, possible guiding personnel, dynamic traffic restrictions and other traffic management measures on the road network affected

The data items depend on the nature and impact of the event. For a frequently recurring sport event such as a football or ice hockey match, cities typically take routinely into use specific traffic management schemes (e.g. a specific traffic signal scheme) to deal with the sudden surge of traffic originating from the arena at the end of the event. No additional information may be disseminated. For a less frequent event such as an annual marathon run or a music festival, all data items listed above can be relevant.

The transport or land use authority or the road operator may set the organiser of the event specific requirements concerning the provision of event management and information as a condition for the changes in transport system requested by the organiser concerning e.g. guidance to event site. A digital shadow of the event's transport system features can be required for events with major transport system impacts lasting for several days. Otherwise a digital model can be sufficient.

5.3.2 Electronic/Digital traffic rules/regulations

General traffic regulations

General traffic regulations refer to set of rules for how road users keep traffic safe and in good flow; these rules include for example traffic signals and signs. The following means of data provision have been identified as a source of general traffic regulations:

- Electronic traffic regulation databases from regulation disseminator (see e.g. Management of Electronic Traffic Regulations (METR) and Soni & Reshad 2025)
- Road traffic signs which can be machine readable by a system(s).
- Traffic signals

The key types of information attributes in general traffic regulations for the NRAs are as listed in Soni & Reshad (2025) category of traffic rules:

- User, e.g. seat belt
- Vehicles, e.g. size of vehicles
- Roads, e.g. position, signs
- Activities, e.g. turning, parking
- Environment, e.g. pedestrian crossing, school zone
- Happenings, e.g. accidents
- Interactions, e.g. priority to the right

Traffic rules and regulations from local, regional and federal regulators can be collected and digitalised to electronic traffic regulation databases, which can be in responsibility of the NRAs, depending on national responsibilities and decisions. Vehicles and services may also collect traffic rules by machine reading road signs, e.g. speed limits. Traffic signals are often in responsibility of local road operators and municipalities.

Speed limits

Speed limits refer to maximum and minimum speed by law on a road which is presented with a traffic sign. The following means of data provision have been identified as a source of speed limits:

- Electronic traffic regulation databases from regulation disseminator (see e.g. Management of Electronic Traffic Regulations (METR) and Soni & Reshad 2025)
- Road traffic signs which can be machine readable by a system(s).

The key types of information attributes in speed limits for the NRAs are:

- Speed limit
- Location
- Duration in distance

Speed limit and its location is often available in the NRA road infrastructure database and should be shared openly. Additional machine readable information sources and attributes can be collected and made available by the NRA, municipalities and private industry.

Access Control / UVAR

Access Control / UVAR refers to Urban Vehicle Access Regulations (UVAR) which regulates vehicular access to urban infrastructure. The following means of data provision have been identified as a source of access control and UVAR:

- Electronic traffic regulation databases from regulation disseminator (see e.g. Management of Electronic Traffic Regulations (METR) and Soni & Reshad 2025)
- Road traffic signs which can be machine readable by a system(s).

The key types of information attributes in access control and UVAR for the NRAs are (adapted from UVAR Box 2021):

- Location
- Validity
- Description
- Issuing authority
- Reason
- Regulation
- Status

Access control and UVAR information can be provided the NRA road infrastructure database, if the information is available. Additional machine-readable information sources and attributes can be collected and made available by the NRA, municipalities and private industry.

5.3.3 Signal control and hard shoulder

Signal control

Signal control, which acts a source and refers to traffic signal control and its systems to real-time automation of lights to optimise traffic flow and safety. The key types of information attributes in Signal control for the NRAs are (adapted from USDOT):

- Traffic signal, e.g. type, location, structure, power
- Signal head, e.g. type, configuration
- Controller, e.g. type, make, model

- Communication devices, remote communication, device type, system type
- Detection system, e.g. loop size, type, camera and radar type
- Signal type plan, updated, parameters

Signal control responsibility and control is with NRAs and local municipalities. Signal control information sharing often depends on the chosen solutions and contracts with the service provider of the signal control system.

Hard shoulder running

Hard shoulder running (HSR) refers to dynamic use of hard shoulders as an extra driving lane with the aim to increase road capacity in times of high traffic demand (CEDR 2018). The following means of data provision have been identified as a source of HSR:

- NRAs static physical infrastructure information databases or National Access Points
- Industry OEMs and service providers databases of static physical infrastructure information.
- Dynamic information about use of the hard shoulders can also be provided for example via loop detectors, cameras and probe vehicle data.

The key types of information attributes in hard shoulder running for the NRAs are (adapted from Ma et al. 2016):

- Location of the hard shoulder
- Length of the hard shoulder
- Vehicle restrictions
- HSR status availability
- Validity and open/closure time

NRA has often collected and stored static and dynamic data of hard shoulder, as a part of the physical infrastructure data it manages, which it also should share openly to road users.

5.3.4 Summary of traffic management related data items

The Table 6 below presents summary from this chapter of traffic management related traffic data with sources and information attributes that are often in road operator responsibility. The table does not aim to make a comprehensive summary, but to provide an overview.

Table 6 Summary of traffic management related data sources and attributes that are often in road *operator responsibility.*

Traffic management Digital representation use case	Relevant data sources and information attributes often in road operator responsibility
Common operational picture for traffic management (network level use case)	
- Traffic jam conditions and end of queue	Sources: Roadside units, sensors and ITS Attributes: speed, flow, time, occupancy, density, location, queue length, duration
- Surface condition monitoring	Sources: Roadside units, sensors, ITS, road weather stations Attributes: friction, temperature, humidity, location(s), maintenance activities
- Tunnel closure and management	Sources: ITS, roadside units, sensors, cameras Attributes: air quality and pressure, visibility, airflow, temperature, vehicle speeds, weather data
- Road works	Sources: NRA databases of road works information, trailers, maintenance vehicles Attributes: type of road work, location, lane or lanes impacted, validity time
- Safety related incidents and incident management	Sources: Roadside cameras and roadside units/ITS Attributes: location, type of incident, status, severity, duration, affected area/road/lane
- Incident detection	Sources: Roadside cameras and roadside units/ITS Attributes: Incident location, lane(s), type, status, duration, detour(s)
- Event management	Sources: event data Attributes: type, location, timing, affected roads, transport service changes, traffic management plan
Electronic/Digital traffic rules/regulations	
- General traffic regulations	Sources: electronic traffic regulation databases, road traffic signs that machine readable, traffic signals Attributes: user, vehicle, road, activities, environment, happenings, interactions
- Speed limits	Sources: electronic traffic regulation databases, road traffic signs that machine readable Attributes: speed limit, location, duration in distance
- Access Control / UVAR	Sources: electronic traffic regulation databases, road traffic signs that machine readable, traffic signals Attributes: location, validity, description, issuing authority, reason, regulation, status
Signal control	Sources: traffic signal and control Attributes: traffic signal, signal head, controller, communication devices, detection system, signal type
Hard shoulder running	Sources: NRAs static physical infrastructure databases and dynamic data databases of HSR Attributes: location, length, vehicle restrictions, status and availability, validity and open/closure time

5.4 *Information provision to external services*

Automated traffic enforcement

In the automated traffic enforcement, the law enforcement authority is the natural host of the digital shadow. Depending on national agreements, the road authorities and traffic managers may also act as the hosts in cooperation with the law enforcement agencies.

Key data items are to be derived from the applicable (digital) rules of the road and the individual vehicle behaviour in its context (time, location, situation, etc), as any discrepancy potentially leads to enforcement triggers.

Key data items for speed enforcement are the applicable speed limits for the right place and time of day as well as the category of vehicle that the speed limit relates to. To successfully determine whether a vehicle is exceeding the speed limit an accurate measurement of the vehicle's velocity (either point or trajectory) is needed with and agreed error of margin and correct identification (picture) of the vehicle to pursue enforcement. The legal framework and therefore specific data items may differ per EU member state. (Safety-Net 2009)

For Urban Vehicle Access Restrictions (UVAR) there's a guideline developed in the UVAR-box (2021) project which consists key data items such as:

- RoadCondition,
- OccupantCondition,
- DriverCondition,
- AccessCondition,
- LocationCondition,
- ValidityCondition,
- VehicleCondition,
- NonVehicularRoadUserCondition,
- PermitCondition,

HD Map

Land use authorities and road operators typically host digital map models of their infrastructures as basic foundations of their own core business. The digital shadow type of HD maps are hosted by commercial digital map providers responsible for the development, operation and maintenance of the digital maps.

The automated driving systems and fleet operators may provide update proposals for the digital shadow contents in the case of anomalies detected. The vehicle fleet operators likely also operate their own digital shadows building on top of HD maps but containing ODD-related geofences and other additional attributes relevant to their fleet.

Key data items can be divided into (quasi) static and quasi (dynamic) geographical information. In Europe, TN-ITS focuses on exchanging static road attributes described in the RTTI Delegated Regulation. Speed limits information has the highest priority, followed by lane information, road name, restrictions, warnings, etc. Information can be shared as line attributes or as point attributes (reflecting traffic signs).

Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness (DOVA)

As the automated driving systems can operate safely only within their Operational Design Domain (ODD), they need to be always aware of the status of each ODD attribute in their location and their possible position at least during the next 10 seconds (Ko et al. 2024). The solution proposed to accomplish this is to use the Distributed ODD attribute Value Awareness or DOVA concept, developed by CEDR project TM4CAD. Deliverable D4.1 “Implementation aspects of Distributed ODD attribute Value Awareness” (Vreeswijk et al., 2023) describes various use cases and the related data items. Two frequently used use cases where externally sourced information is deemed beneficial for automated vehicles are the road works and tunnel use case.

Use case introduction	
Summary	A vehicle operated by an ADS approaches a roadwork zone.
Background	It is assumed that without an intervention the ADS will approach and detect the roadwork zones, observe that the local conditions do not match the ODD of the system, and transfer the dynamic driving task to the driver in case of a Level 3 ADS. In case of a Level 4 system the ADS will make a minimal risk manoeuvre. .
Objective	Timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.
Desired behaviour	The ADS can travel through the roadwork zone as normal, or it can transfer the control of the vehicle to the driver in a safe and timely manner. In case of the latter, the driver operates the vehicle through the roadwork zone.
Expected benefits	With less ODD fragmentation, the ADS developer can provide better continuity of service and thereby improve its competitiveness via improved attractivity to the vehicle buyer. In other instances, the ADS developer can provide a smoother service when the dynamic driving task needs to be transferred to the vehicle driver. The driver can experience better continuity of services, without fewer interventions caused by transfer of control requests. In case the dynamic driving task does need to be transferred to the vehicle driver, the driver can experience a more user-friendly and informative service compared to the case with unexpected takeover requests. The road operator/traffic manager experiences fewer minimal risk manoeuvres by ADS and fewer accidents in roadwork zones due to safer driving behaviour of ADS.
Use case description	
Situation	2-lane motorway with hard shoulder, with a roadwork zone on the left driving lane. Traffic is diverted to two narrower driving lanes using the right lane and the hard shoulder. Maximum driving speed in the roadwork zone is 70 kmh.
Actors and relations Note: actors are roles and not to be confused by stakeholders; an	ADS: performs the dynamic driving task and uses on-board and off-board sensors to create situational awareness. Upon detection of the roadwork zone the ADS assesses if it is capable to operate in the local conditions. If not, the system will request the vehicle driver to take over the dynamic driving task. Vehicle driver: is not performing the dynamic driving task. In case of a L3 system the driver must be available to resume the driving task when

actor role can be fulfilled by any stakeholder (e.g. NRA), one stakeholder can have multiple roles.	requested, in case of a L4 system the driver does not have to be available. The driver resumes the dynamic driving task if the ADS requests them to do so and if the driver is capable to do so. Road operator/traffic manager: operates the motorway by means of roadside systems and TMC services. It publishes information about the roadwork zone via different communication channels to information service providers, vehicle systems and vehicle drivers. Roadworks contractor: manages the road works site including the local traffic management via cones, signs and road markings. It can also provide real time information about the location and topology of the road works site. Its contract with the road operator specifies the obligatory actions that it needs to carry out. Information service provider: third-party information broker or vehicle fleet operator that facilitates the exchange of information between road operators and fleet of vehicles which are operated by either vehicle drivers or ADS.
Use case scenario	Scenario 1: allow timely handover The road operator or traffic manager maintains and publishes an overview of the location of roadwork zones based on information provided by roadworks contractors. An information service provider ensures that the information is available to ADS. Upstream of the roadwork zone the ADS receives information about the presence of the roadwork zone. As the ADS is not designed to operate in roadwork zones, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resume the dynamic driving task. An alternate outcome for this scenario is that the ADS plans an alternative route and avoids the roadwork zone. Scenario 2: interpret the roadwork zone The road authority maintains and publishes *descriptive* information about roadwork zones such as precise location, speed limit, lane permissions and restrictions, etc. based on information provided by roadworks contractors. An information service provider ensures that the information is available to ADS. Upstream of the roadwork zone the ADS receives the descriptive information of the roadwork zone. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving possibly with adapted driving behaviour, if not it requests the vehicle driver to take over de dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. Scenario 3: guided through the roadwork zone The road operator maintains and publishes *detailed* information about roadwork zones such as the road and lane topology, lane permissions and restrictions, presence of objects and barriers, recommended trajectory, etc. based on information provided by roadworks contractors or probe vehicles that already passed the roadwork zone. An information service provider ensures that the information is available to ADS. Upstream of the roadwork zone the ADS receives the detailed information about the roadwork zone. The ADS assesses if it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving possibly with

	adapted driving behaviour, if not it requests the vehicle driver to take over de dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task.
Functional constraints / dependencies	The information about roadwork zones must be captured and maintained. This is a responsibility of the road operator who is likely to outsource data capture and update tasks to the contractor in charge of the roadworks. Such data, e.g. recommended trajectory information, may be collected and provided by probe vehicles who already passed the roadwork zone (ADS operated or manually driven). Information service providers may be in the best position to collect driving history information from vehicle fleets. The road works zone information must be available digitally with sufficient level of accuracy and timely updates in case of changes. Information can be delivered to the ADS in several ways. One way is to build upon C-ITS deployment practices as documented by C-Roads and using C-ITS messages DENM, IVIM and MAPEM. Aside from direct short-range communication, information may flow through National Access Points and other backends of a third-party information broker and/or vehicle fleet operator. Alternatively, there may be a place and role for a Digital Twin, which is further elaborated by the CEDR 2020 DiREC project.

Use case introduction	
Summary	A vehicle operated by an ADS approaches a tunnel or is driving in a tunnel.
Background	It is assumed that without an intervention the ADS will approach and detect the local conditions at the tunnel entry or exit, observe when the local conditions do not match the ODD of the system, and transfer the dynamic driving task to the driver in case of a Level 3 ADS. In case of a Level 4 system the ADS will make a minimal risk manoeuvre. .
Objective	Timely transfer of the dynamic driving task to the driver in case of Level 3 ADS (and thereby decrease the risk of minimal risk manoeuvre in case the driver does not respond) or avoid the need for a transfer of control entirely. In case of Level 4 ADS the objective is to avoid the minimal risk manoeuvre or to achieve a safer minimal risk condition.
Desired behaviour	The ADS can handle the tunnel situation as normal, or it can transfer the control of the vehicle to the driver in a safe and timely manner. In case of the latter, the driver operates the vehicle at the tunnel situation.
Expected benefits	With less ODD fragmentation, the ADS manufacturer can provide better continuity of service and thereby improve its competitiveness via improved attractivity to the vehicle buyer. In other instances, the ADS manufacturer can provide a smoother service when the dynamic driving task needs to be transferred to the vehicle driver. The driver can experience better continuity of services, with fewer interventions caused by transfer of control requests. In case the dynamic driving task does need to be transferred to the vehicle driver, the driver can experience a more user-friendly and informative service compared to the case with unexpected takeover requests.

	The road operator/ traffic manager experiences fewer minimal risk manoeuvres by ADS and fewer accidents near or in tunnels due to safer driving behaviour of ADS.
Situation	2-lane motorway without hard shoulder with a tunnel with a length of 3 km. In the first scenario the ADS-operated vehicle is 2 km upstream of the tunnel and approaching, and the tunnel is temporarily closed due to an incident. In the second scenario the ADS-operated vehicle is driving in the tunnel.
Actors and relations Note: actors are roles and not to be confused by stakeholders; an actor role can be fulfilled by any stakeholder (e.g. NRA), one stakeholder can have multiple roles.	ADS: performs the dynamic driving task and uses on-board and off-board sensors to create situational awareness. Upon detection of the local conditions at the tunnel entry or exit the ADS assesses if it is capable to operate in the local conditions. If it is not, the system will request the vehicle driver to take over the dynamic driving task. Vehicle driver: is not performing the dynamic driving task. In case of a L3 system the driver must be available to resume the driving task when requested, in case of a L4 system the driver does not have to be available. The driver resumes the dynamic driving task if the ADS requests them to do so and if the driver is capable to do so. Road operator/traffic manager: operates the motorway and tunnel by means of roadside systems and TMC services. It publishes information related to the tunnel via different communication channels to information service providers, vehicle systems and vehicle drivers. Information service provider: third-party information broker or vehicle fleet operator that facilitates the exchange of information between road authorities and fleet of vehicles which are operated by either vehicle drivers or ADS.
Use case scenario	Scenario 1: approaching a closed tunnel, allow timely handover The road operator or traffic manager monitors tunnels continuously and publishes detailed information of temporary tunnel closures when an incident occurs. An information service provider ensures that the information is available to ADS. Upstream of the tunnel and the tunnel's signalling systems, the ADS receives information about the closure of the tunnel. As the ADS is not designed for this condition, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resume the dynamic driving task. Scenario 2: interpret the closed tunnel condition The road operator or traffic manager monitors tunnels continuously and publishes detailed information about tunnel closures. An information service provider ensures that the information is available to ADS. Upstream of the tunnel and the tunnel's signalling systems, the ADS receives information about the closure of the tunnel and active diversions via other lanes and/or tunnel tube. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, the ADS continues the dynamic driving task and stops the vehicle in the queue at the tunnel's signalling system or follows the active diversion. If not, it requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. An

	alternate outcome for this scenario, in particular when the duration of the tunnel closure is known, is that the ADS (likely the information service provider) plans an alternative route and avoids the tunnel. Scenario 3: approach tunnel exit, allow timely handover The road operator or traffic manager maintains and publishes detailed information about local conditions at tunnel exits (e.g., weather, incidents or lighting) based on information provided by roadside equipment. An information service provider ensures that the information is available to ADS. Upstream of the tunnel exit the ADS receives information about the local condition at the tunnel exit. If the ADS is not designed to operate in those conditions, it requests the vehicle driver to take over the dynamic driving task. The vehicle driver has enough time to respond and safely resumes the dynamic driving task. If the driver fails to respond the ADS will perform an MRM. Scenario 4: interpret the tunnel exit condition The road operator or traffic manager maintains and publishes *descriptive* information about local conditions at tunnel exits (e.g., weather, incidents or lighting) based on information provided by roadside equipment. An information service provider ensures that the information is available to ADS. Upstream of the tunnel exit the ADS receives information about the local condition at the tunnel exit. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving possibly with adapted driving behaviour (e.g. reduced driving velocity) or in-advance activation of functions that will mitigate the effects of the local condition on the ADS capability (e.g. heat the sensors). If not, the ADS requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. If the driver fails to respond the ADS will perform an MRM. Scenario 3: guided through the tunnel exit condition The road operator or traffic manager maintains and publishes *detailed* information about local conditions at tunnel exits (e.g. weather, incidents or lighting) based on information provided by roadside equipment. In addition, the road operator or traffic manager activates road management (e.g. lane closure) and/or traffic calming measures (e.g. reduced speed), which are also published. An information service provider ensures that the information is available to ADS. Upstream of the tunnel exit the ADS receives information about the local conditions at the tunnel exit. The ADS assesses whether it can operate in the local conditions ahead with the additional information it received. If yes, it continues driving, possibly with adapted driving behaviour, if not it requests the vehicle driver to take over the dynamic driving task. In that case, the vehicle driver has enough time to respond and safely resume the dynamic driving task. If the driver fails to respond the ADS will perform an MRM.
Functional constraints / dependencies	Local condition information must be collected and frequently updated. This is a responsibility of the road authority who may use their own infrastructure sensors complemented with data from third-party service providers (e.g. meteorological institute and floating vehicle data). The local condition information must be available digitally with sufficient level of accuracy and

	timely updates in case of changes. Communication and connectivity require special attention in the case of local conditions at tunnel exits. As there may be no (mobile network) coverage in the tunnel, connectivity relies on short-range communication technologies for which reflection of radio waves should be taken into consideration. Alternatively, information may be delivered to the ADS before entering the tunnel with the risk of being outdated by the time the ADS exits the tunnel. In case of such long tunnels, it is necessary to deliver local condition information to ADS when they are driving in the tunnel. One option may be the use of visual signalling inside the tunnel which can be read by the ADS as well as by human drivers. Information can be delivered to the ADS in several ways. One way is to build upon C-ITS deployment practices as documented by C-Roads and using C-ITS messages DENM, IVIM and MAPEM. Aside from direct short-range communication, information may flow through National Access Points and other backends of a third-party information broker and/or vehicle fleet operator. Alternatively, there may be a place and role for a Digital Twin which is further elaborated by the CEDR 2020 DiREC project.

6 KPIs for process improvement by digital twins

Key Performance Indicators (KPIs) will be defined in order to analyse or predict to what extent specific (operational) NRA services can improve by using digital representations of the road infrastructure. The general assumption is that digital representations make road infrastructure related processes of the road operators more efficient. This in turn would bring considerable socio-economic benefits.

A performance indicator can be defined as an item of information collected at regular intervals to track the performance of a system. Performance Indicators (PIs) do not provide perfect measure of the system they are measuring as errors and problems of definition and interpretation can occur. Nevertheless, PIs provides pointers to the functioning of the system as a part of quality control. (Fitz-Gibbon 1990)

Key Performance Indicators (KPIs) are critical (key) indicators that present quantitative information of progress toward an intended result, i.e. understanding what's happening in the business and how to improve. KPIs offer focus for strategic and operational improvement and support decision making to focus attention. Targets are set for the KPIs for desired level of performance which are then tracked. There are usually a lot of indicators and measures to consider as no single metric or set of metrics provide right information for every service. A good understanding of what is important to the organisation and its customers is required. (Harlow n.d., CA Technologies 2015)

Intelligent Transport Systems (ITS) performance indicators, i.e. measuring success of ITS scheme and linked to the objectives that the ITS is aiming to achieve, have been presented by the World Road Association (PIARC n. d.). Example of critical factors analysis is presented in the table below to show how indicators are linked to goals.

Table 7 Examples of critical factors analysis of measures (indicators) link to goals (PIARC n. d.)

Goal area	Example measure
Safety	Crashes / fatalities
Efficiency	Throughput / Travel time savings / Reliability
Mobility	Accessibility of opportunities / Inter-modal connections
Productivity	Cost savings
Energy and environment	Emissions and fuel consumptions
Customer satisfaction	Opinions, patronage

PIARC gives further advice on how to choose performance indicators which are summarised with few adaption notes and examples in the list below:

- <u>Common indicators</u>: Commonly used measures, such as agreed nationally or within a road authority (editor note: or European) helps to compare between schemes.
- <u>Types of indicator</u>: Indicator must be defined in quantifiable terms. Qualitative measures, such as users' perceptions, can be quantified.
- <u>Advice to practitioners</u>: Review other evaluation projects when deciding on the indicators to be used, e.g. most suitable indicators for specific objects to be used with potential sources of data. PIARC also refers to previous critiques of using indicators that are ambiguous and biased or even illogical.

Evaluation guidelines are referred by the PIARC (n.d.) as a useful source of indicators. The following guidelines were referred by PIARC and identified from the literature which also were partly used as a basis for the analysis in this chapter:

- EasyWay Project Evaluation Guidelines
- CONDUITS – Key performance indicators for traffic management and ITS
- Transport Analysis Guidance
- US DOT ITS Knowledge Resources
- United Kingdom ITS Toolkit

From the above-mentioned guidelines, closer look is taken to the EasyWay and its follow-up EU EIP results. The PIARC refers to earlier EasyWay project guidelines' proposed performance indicators;

- network and costs
- vehicle fleets and costs
- time and predictability
- accessibility
- valuations for comfort
- noise emissions and energy
- traffic safety

The EasyWay was a predecessor project together with EIP+ for EU EIP. In addition, European Commission DG Move report on ITS KPIs (2016) being referred as more 'generic' and included in the KPI comparison, was reviewed in the EU EIP work. Therefore, the EU EIP results are further analysed and used in this study.

The European ITS Platform (EU EIP) project publication on ITS Deployment and Benefit KPIs definitions with technical reference includes the following ITS priorities and benefits which are a summary of ITS Priority Areas or Benefit categories from AECOM (2015) report which were further applied in the EU EIP classification of KPIs (Marsili et al. 2017):

- Optimal use of road traffic and travel data (Deployment KPIs – comprehensiveness of offering of ITS data to users)
- Continuity of traffic and freight management ITS Services (Deployment KPIs – seamless ITS Services to Private/Public Transport/Freight users)
- Road safety and security applications (Deployment KPIs – comprehensiveness of offering of ITS equipment to users)
- Linking the vehicle with the transport infrastructure (Deployment KPIs – comprehensiveness of offering of ITS equipment to users)
- Network efficiency and congestion (Benefit KPIs)
- Improving Environmental impacts (Benefit KPIs)
- Improve road Safety (Benefit KPIs)
- Enhance modal Integration (Benefit KPIs)

Digital twins' KPIs in road planning and for data analysis and model development are discussed by Buuveibaatar et al. (2023) who suggest performance metrics to evaluate the feasibility of digital twins such as scalability (e.g., system performance vs. data volume), quality metrics such as the results or accuracy of prediction digital twin yields, and cost-related metrics such as software/platform cost, development cost, and labour cost. The forementioned examples are presented as planning objectives with performance goals and performance indicators in Figure 2.

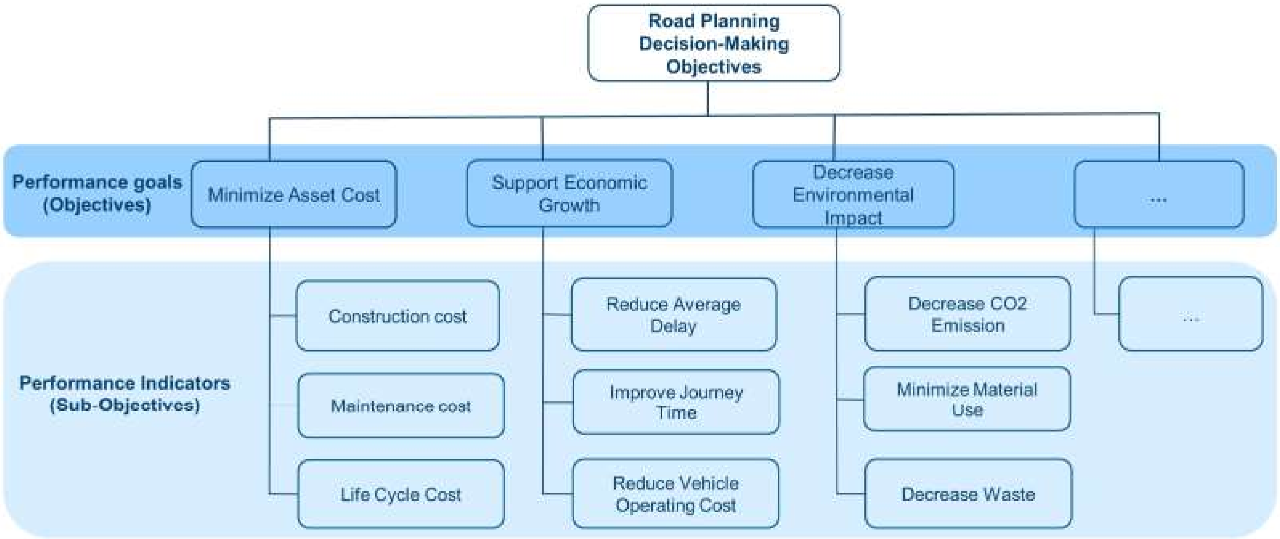

Figure 2 Planning objectives tree example by Buuveibaatar et al. (2023).

Benefits of ITS and especially still developing digital representations as well as digital twins are quite difficult to predict in advance and expert judgements are needed to predict the likely economic impacts as indicated by the Finnish case example (Kulmala 2021) below.

The Finnish activity contains the development of an enhanced digital road data base and the deployment of the digital model on motorways and for specific features of other TEN-T roads including the development of the data production processes. This is the first phase of the Digital Twin to cover the whole public road network and also the dynamic real-time layers of the digital twin. The costs of the first phase of the digital twin would be about 5 M€, and the annual operation and maintenance costs could be around 15% of the investment costs.

In 2019, the total expenditure of the Finnish Transport Infrastructure Agency FTIA on road transport infrastructure and related services was 982 M€. There are no benefit cost assessments of the operation of the FTIA, but it is likely socio-economically very feasible.

The effects of the digital twin have been listed below:

- enhances the effectiveness of planners, builders, users, and maintainers in all parts of the lifecycle of road network infrastructure and operations
- provides a reliable digital copy of the state and properties of the road infrastructure throughout its lifespan
- facilitates the real-time situational picture and reporting of the infrastructure level of service, condition, and use
- enables well timed and informed maintenance of the infrastructure
- facilitates the prediction of incidents and disturbances on the road network, and the preparedness of the road operator
- improves risk management
- improves the level of service offered to road users

The impacts above are estimated to result in the first phase the following effects on the effectiveness of operations financed by FTIA

- road and winter maintenance 0.5 – 2%
- (total impacts of the digital twin for the whole transport system 10-20%)
- road planning 0.2 – 0.5 %
- road building 0.3 – 0.6 %
- asset management 1 – 4 %
- traffic management 0.1 – 0.2 %

In all the benefits of FTIA are estimated to improve 0.4 – 1.6 %. If the current benefit to cost ratio of FTIA road operations is at least 1, this would mean that the annual benefits in 2019 would have been between 6.0 and 15.7 M€. This would mean that the costs of the deploying, operating, and maintaining the first phase of the digital twin would be covered by the benefits in less than two years. The benefit/cost ratios are from 8.7 to 26.6 for the benefit improvements of 0.4 and 1.6 %, respectively.

6.1 Building and planning

The road operators can monitor the process improvement by digital twins during the design and construction phase using the following KPIs:

BIM maturity levels (Bew and Richards, 2008**)** - The UK Code for BIM defines the BIM maturity levels from level 0 (no collaboration) to level 3 (full collaboration). Figure 2 showcases the wedge diagram of BIM technology maturity levels as defined by Bew and Richards (2008).

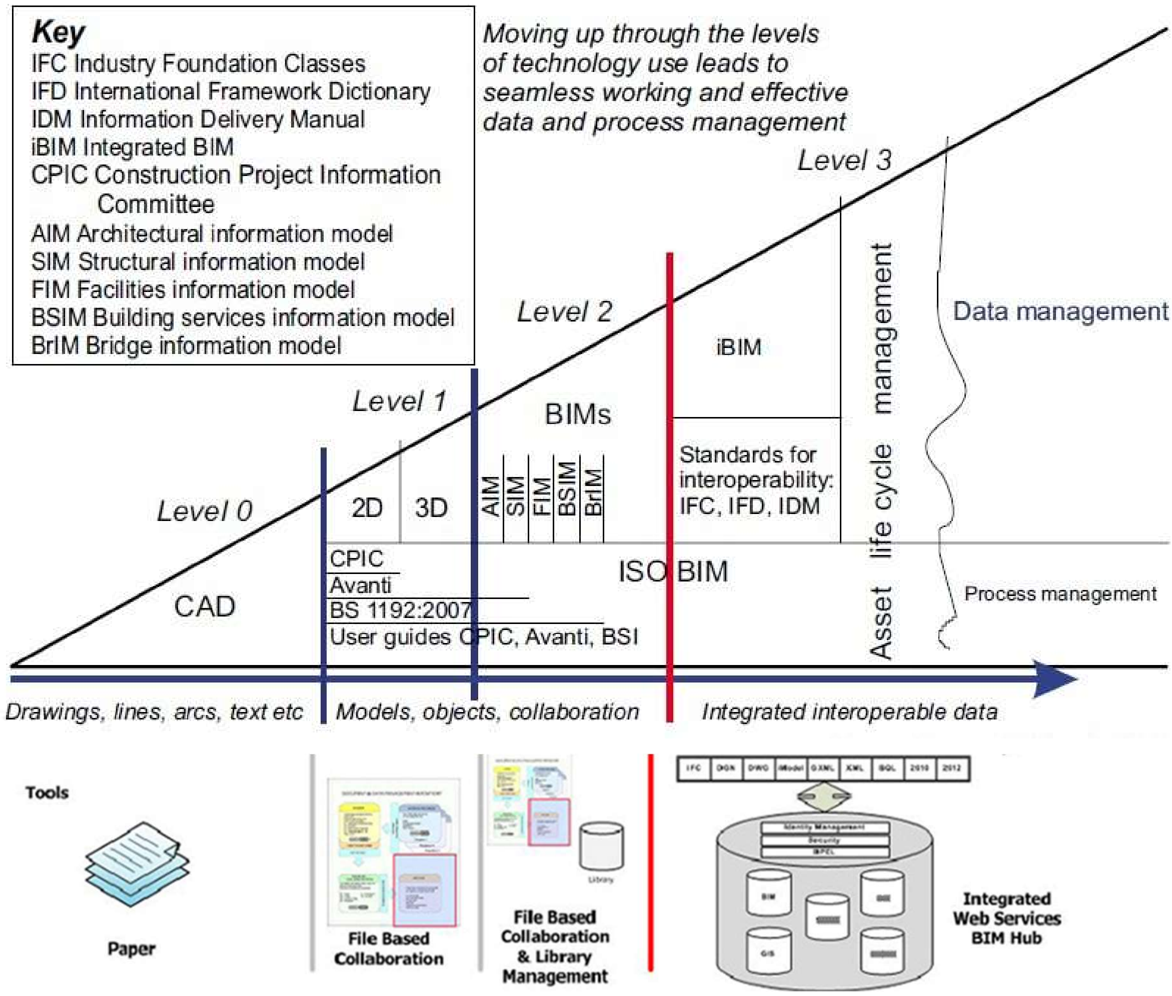

Figure 2: BIM Technology Maturity Levels (Bew & Richards, 2008)

These levels describe the progression of BIM maturity, from basic CAD (Level 0) to fully integrated, cloud-based collaboration (Level 3), with incremental steps involving 3D modeling and data sharing (Levels 1 and 2). Tracking a road operator's movement through these BIM levels serves as a crucial KPI because it directly reflects their efficiency, collaboration, and technological advancement. Progressing to higher BIM levels signifies improved data management, reduced errors, enhanced stakeholder communication, and ultimately, more cost-effective and sustainable infrastructure projects.

Faster design review cycles - Digital twins enable faster visualization and analysis. Measure the time taken to review and approve designs.

Reduced construction costs[1] **-** Cost savings achieved through improved material estimation, optimized scheduling, and reduced rework.

Improved prediction of potential issues (Attaran & Celik, 2023) **-** The ability of the digital twin to accurately predict issues such as clashes or conflicts

Reduction of Project Delays - Measure the amount of time saved in the projected schedule.

[1] https://www.dreso.com/at/en/news/details/up-to-ten-percent-lower-construction-costs-with-digital-twin

6.2 Asset management and maintenance

Some KPIs to monitor the improvements due to digital twin which can be utilised by the road operators are:

Optimized maintenance scheduling - Reduction in unplanned road closures, increased efficiency of maintenance crews. Predictive maintenance capabilities of digital twins allow for proactive interventions.

Reduction of costs[1] - Costs of inspection, maintenance, and repairs, in comparison to the costs prior to digital twin implementation.

Improved asset condition monitoring (Hagen & Andersen, 2024) - Frequency and accuracy of asset inspections, early detection of defects. Sensor data and digital twin analysis provide continuous monitoring.

Predictive maintenance accuracy[2] - How well the digital twin predicts the need for maintenance, and how well those predictions match real world required maintenance.

Amount of maintenance assets used – The amount of salt used for winter maintenance of roads was used to measure the impacts of mobile road surface condition data by Zachrisson (2017). The result was a 5 – 15 % reduction.

6.3 Traffic management

This chapter evaluates possible Key Performance Indicators (KPIs) for how road operator traffic management services can improve by using digital representations of the road infrastructure.

The expected impact and improvements for traffic management by digital twins is discussed by Wu et al. (2025) who describe how digital twins can provide real-time data on integrations and simulation capabilities to optimize the flow of traffic without congestion and improve safety. Digital twins can integrate data from thousands of sensors and cameras to support real-time adjustments in signals and route planning. Additionally, application of digital twins in predictive analytics in traffic conditions and congestion, can enable pre-emptive traffic control measures, such as traffic signal timings may improve flow and safety. Simulations with replicas of the on-road conditions can be created to enhance decision-making.

Since the digital representations are still evolving and according to the previous results of the study (Soni et al. 2025) there isn't much experience on the usage of the models, especially digital twins. Therefore, this will impact the analysis in two ways: first, digital representation use cases are not individually evaluated, but rather a common evaluation of available and possible KPIs are presented and discussed; secondly, performance indicators or KPIs related to traffic management include most common ones found and merged from literature.

Intelligent Transport Systems (ITS) KPIs were discussed in the introduction of this chapter where the World Road Association (PIARC n. d.) Intelligent Transport Systems (ITS) performance indicators were presented with links to the objectives that the ITS is aiming to achieve. The critical factor analysis measures included for example, crashes and fatalities, throughput and travel time, accessibility of opportunities, cost savings, emissions and opinions. Many of the mentioned higher level or 'generic' measures introduced by PIARC, can also be

[2] https://www.mckinsey.com/industries/infrastructure/global-infrastructure-initiative/roundtables/europe-2024-harnessing-the-power-of-predictive-maintenance-in-roads

found from the previous European KPI studies which are presented next.

EU EIP Deployment KPIs mostly include calculation of length and % of road network (TEN-T and/or National) covered or impacted by the KPI in question, e.g. incident detection and management, automated speed detection, intelligent vehicles, speed limit information, etc. Since the deployment KPIs mainly consist of statistical information on how the deployment is advancing, the usefulness for digital representations is seen limited. There might be cases where the digital model can bring accuracy to the KPI, for example KPI for hard shoulder running length and % of road network could be measured with a model more accurately, but this is estimated being very limited. (Marsili et al. 2017)

EU EIP Benefit KPIs include for example absolute and % changes in the KPI in question. The Benefit KPIs were all evaluated being related to traffic management and therefore here reviewed. The below table presents the benefit KPIs with long name and discussion of possibilities how road operator traffic management services can improve by using digital representations. (Marsili et al. 2017)

Table 8 EU EIP Benefit KPIs name summaries. (Marsili et al. 2017)

EU/EIP Benefit KPI	Benefit KPI name summary
Change in traffic flow	Change in traffic flow (e.g. vehicles per hour/day at spot location), measured at specific locations of the road network (TEN-T and/or National) affected by the implementation of the relevant ITS system affected by the implementation of the relevant ITS system.
Change in road traffic journey time variability	Change in journey time variability as measured coefficient of variation (standard deviation of the measured travel times for a certain route or a part of a route).
Change in Bottleneck Congestion	Congestion (LOST VEHICLE HOURS / TIME SAVING): Total delay or vehicle hours lost expressed as the difference between the total time spent and a weighted (with the flow) reference (free-flow) journey time.
Change in Journey Time	JOURNEY TIME: Journey time is the indicator to determine the impact of a measure on the road users.
Change in demand for travel	Difference in Vehicle-km driven: The distance travelled or vehicle kilometres driven is a network indicator and is defined as the product of the length of a road section and the flow on that road section.
Change in mode share	Change in mode share (% mode share points) on corridors where ITS has been implemented.
Change in accident numbers and severity	Absolute and % change in number of reported accidents of all severities as well as accident rates (i.e. accidents per vehicle-km travelled).
Change in CO_2 emissions	Change in annual CO_2 emissions (Tons) (absolute and % difference).
Public eCall timeliness	Total time taken between: accident occurrence to initiation of public (112) eCall to the presentation of the content of MSD in an intelligible way at the operator's desk in the Public Safety Answering Point.
Change in Noise Pollution	Noise Reduction: ITS impact considered negligible

Digital twins' performance and KPIs with factors affecting in Architecture, Engineering, and Construction (AEC) projects is discussed by Kosasih (2024) who suggests the following with examples, e.g. computer networking and manufacturing as well as infrastructure, to show how accurate, efficient and overall impact on operations the digital twins can provide:

- **Predictive accuracy**: how well the digital twin simulations and forecasts match what actually happens in the real world.
- **Data Integration**: how the digital twin processes real-time data from different sources to keep the digital representation of the physical entity up to date and accurate.
- **Operational Efficiency**: more efficient processes, like reducing downtime, increasing throughput and using resources better.
- **Cost Reduction**: reduce maintenance costs by spotting when equipment is about to break and schedule maintenance when needed.
- **Adaptability**: adapt to changes in the physical environment quickly, e.g. configuration updates.

A standardised approach for measuring the performance and flexibility of digital twins is presented by Psarommatis & May (2022) who present the following generic KPIs of digital twins:

- Accuracy of the digital twin: Relative difference between the estimated value provided by the digital twin model and the actual value produced by the modeled system. The accuracy is measured to determine the precision of the digital twin output parameters.
- Accuracy variance: Repeatability of the digital twin model. More specifically, the variance of the digital twin accuracy in the testing sample. The digital twin model might perform better in a certain range of input parameters than in another range.
- Response time: Average time required for the digital twin model to estimate the output parameters for the testing sample.
- Response time variance: Variance of the response time of the testing sample for evaluating the repeatability in terms of computational time.
- A new KPI of digital twinflex is presented, for determining the flexibility of digital twins for iterative improvement of digital twins to increase their efficiency in future applications. The KPIs above were use case specific, the current approach for evaluating the digital twin flexibility refers to the digital twin methodology and is independent of the use case. The KPI utilises a structured questionnaire to evaluate the flexibility of a digital twin method.

When considering digital twin performance KPIs in traffic management environment, it should be noted that the examples from different industries, such as computer networks and manufacturing industry, although similarities with traffic environment, may not directly translate to traffic environment due to different environments, i.e. closed system of a machine vs. dynamic traffic environment.

Analysis and conclusions of traffic management and digital twins KPIs suggest that the previously studied KPIs for traffic management in Europe, by EU EIP, could also be used by road operator when evaluating traffic management services improvements when using digital representations or twins. Due to complex nature of traffic and traffic management measures, the KPIs and impact of digital twins to traffic management should still be treated with caution as there is still lack of experience on real-world implementations. These conclusions also align with the PIARC (n. d.) advice on how to choose performance indicators: the EU EIP indicators has been commonly agreed in Europe which helps to compare between schemes, the EU EIP measures have been quantified, and further evaluation projects results need to be analysed to find most suitable indicators.

The following analysis concludes Intelligent Transport Systems (ITS) KPIs for how road operator traffic management services could improve by using digital representations of the road infrastructure:

- Safety related KPIs, such as fatalities and change in accident numbers as well as severity
- Efficiency KPIs, such as throughput, travel or journey time savings, change in traffic flow or bottleneck congestion
- Mobility KPIs, such as accessibility of opportunities, i.e. accessibility of destinations through land use and planning as well as infrastructure design.
- Energy and environment KPIs, such as emissions and change in CO2 as well as fuel consumptions, which through simulation and predictive modelling.
- Customer satisfaction, such as opinions, could be quantified and included as a part of the simulations with behavioural analysis.

The following analysis concludes KPIs for how road operator traffic management services could improve by using digital representations of the road infrastructure:

- Accuracy of prediction and its variance, i.e. how well digital twin simulations and forecasts match with the real world.
- Adaptability or flexibility: adapt to changes in the physical environment quickly, e.g. configuration updates.
- Cost-related metrics such as reduction in maintenance costs of e.g. road equipment, software/platform, development and labour. These costs should be compared with the alternative costs, e.g. data platforms and analytical tools.
- Scalability and data integration capabilities of the system, also response time, for example how well the system performs keeping the digital representation of the physical entity up to date and accurate when real-time data volume from different sources increases.

From risk management perspective a bias can occur when evaluating the digital representations simulations results based on the KPIs and with comparison to real-world: not all events happen in the end, but they could happen and therefore they are prepared for and precautions principles are followed.

6.4 Information provision to external services

Automated traffic enforcement, HD map and Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness (DOVA) are three very different services and therefore their associated KPIs are fundamentally different. HD map KPIs are related to the accurate representation of a vehicle's driving environment, whereas the CCAM-DOVA is building upon that by providing contextual awareness for enhanced decision making and thus KPIs can be divided into a category that relates to the ODD, a category that relates to the vehicle's decision making and associated performance and ultimately also a category that describes the vehicles behaviour in terms of safety, efficiency and comfort. Automated traffic enforcement KPIs are on the one hand related to the actual percentage of vehicles that are directly affected by the enforcement (e.g. vehicles "caught" either speeding, or emitting over the limit, or being in an area not permitted) and on the other hand to the intended outcomes of enforcement in terms of safety, impact on the environment and livability, which all have a short term and long term component as it is expected that human (driving) behaviour will alter over time.

Especially for the Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness (DOVA) service, this is uncharted territory and therefor quite early to formulate quantitative KPIs beyond improving traffic safety, increase driver comfort and enhanced driver performance in mixed traffic. Nevertheless, as the main objective of the DOVA concept is to extend the electronic horizon of the ADS, the following KPIs could be candidates to the KPIs:

- number of minimal risk manoeuvres per distance travelled
- number of <10 second threshold time transfers of vehicle control from the ADS to the human vehicle occupant
- number of transfers of vehicle control from the ADS to the human vehicle occupant
- number of disengagements per distance travelled
- number of harsh breaking situations (> 0.3 G)

7 Best practices in making digital twin information available

The best practices were collected via a mail request to the CEDR members in addition to the experiences and learnings from the earlier DROIDS activities.

7.1 Building and planning

Establish standards and guidelines is a key factor in making sure that the information created during the design and construction phase of the project is useable in later stages of the asset's lifecycle. The road operators could emphasize on the implementation of following standards from early stage of the project:

BIM standards: Create or adapt existing BIM standards and guidelines that specify the requirements for data exchange, level of detail, and format (e.g., IFC, openBIM standards).

Collect and standardize BIM data: For past and current projects, gather BIM data, ensuring it meets the standards. Validate the quality of the data, and fill in missing or incomplete information, where feasible.

Adopt ISO 19650: Implement ISO 19650 as the framework for information management and exchange throughout the project lifecycle.

Develop (or use) OTL: Create or use a detailed OTL that defines the properties and attributes of each asset type. This will ensure consistency and interoperability across different projects and organizations.

Standardize Data Formats: Define and use standardized data formats (e.g., Industry Foundation Classes (IFC), Information Delivery Specification (IDS) etc.) to facilitate information exchange and integration. Open standards like IFC and bSDD can ensure interoperability between different software tools and platforms.

A few road operators shared their best practices via questionnaire:

Slovenia is actively integrating advanced digital technologies into its infrastructure projects, moving from pilot 3D bridge models towards mandated BIM implementations. Within their Karavanke tunnel project's they have utilised 5D BIM and CDE portal. Frequently, they utilize LiDAR data for planning and structural analysis, and are researching the fusion of 3D models, LiDAR, and real-time traffic data, aiming for a centralized BIM system and anticipating widespread technology adoption driven by legislation and user system development, including the use of digital twins.x §

Sweden is developing a comprehensive asset management strategy, utilising BIM for road infrastructure and roadside equipment data. This strategy integrates with the National Road Database (NVDB), a system that provides up-to-date information on all Swedish roads, streets, and traffic regulations, with a target update frequency of 24 hours.

In *Switzerland*, road infrastructure data is fragmented across isolated legacy systems, hindering interoperability with modern standards like IFC-5 and CEDR 2018 OTL. This is because these older systems were built for specific, siloed tasks, neglecting data sharing and integration (FAIR principles). While best practice guidelines are still developing, early Proof of Concepts are exploring real-time data integration into IFC and modular Common Data Environments (CDEs) to address this challenge.

In *Finland*, FTIA utilizes a digital road information system, Velho, and a project information portal with Open BIM workflows, integrated with Vektor.io for BIM/GIS visualization. They aim to evolve from a "digital shadow" to a full digital twin, focusing on data flows, quality, interoperability, security, user interfaces, and forecasting. Successful projects like the Kirri-Tikkakoski highway, leveraging Open BIM, demonstrated significant cost savings, accelerated timelines, and improved quality, resulting in substantial budget efficiencies and expanded project scope. FTIA seeks to connect project and asset information using buildingSMART data dictionaries and is looking for best practices and expert contacts from other organizations with similar digital representation deployments.

In Italy, ANAS is implementing 4D and 5D BIM in their projects related to road structures such as bridges. They are currently implementing BIM standard ISO 7817-1 on level of information needs. ANAS has implemented companywide standard ISO 19650 processes within their implementation focusing on the adoption of digital information models, open standards, and the integration of various technologies and requirements as per legislative mandates. Their ultimate goal is to enhance the design, construction, and maintenance processes through improved data reliability and accessibility.

In Iceland, Icelandic Road and Coastal Administration utilises BIM models during the design an construction phase. They have a AIM model which is mostly GIS information and covers the road network for example, alignments, roadside equipment, lane markings etc. They do not have a dedicated digital representation deployment; however, they have utilised the presentation model for various stakeholders in specific design projects where BIM models have been implemented.

In Ireland, TII is in early stages of BIM implementation and they are integrating BIM within their existing developed processes. They have developed processes for asset management and ave their data available in GIS geodatabse in cloud. In terms of ITS equipment they are looking to ensure that any ‘Assets’ managed in a standalone system are also represented in an enterprise Geodatabase as a ‘single source of truth’.

7.2 Asset management and maintenance

As proposed by Heatton and Parlikad (2020), asset information or AIM is crucial in reusing information for creating digital twin. The following practices are recommended to ensure the asset data is useful in digital twin:

Define Information Requirements: Collaborate with stakeholders to identify and document various information requirements (organisational, asset, project and exchange) for each asset from the design stage.

Prioritize Information: Prioritize the information based on its criticality to asset performance and lifecycle management.

Align with OTL: Ensure that the identified information requirements align with the OTL to ensure consistency and data quality.

Simplify Processes: Simplify communication and information delivery processes with contractors to make them more efficient and effective.

Continuous Data Update: Ensure that asset data is kept up-to-date and accurate throughout the asset lifecycle, especially during maintenance phases.

Quality Assurance: Implement mechanisms for validating and verifying data quality to maintain trust and reliability.

7.3 Traffic management

This chapter presents best practices to collect, maintain and distribute traffic management information in such a way that it is compatible with digital twins. Also, best practises are evaluated on how to maintain relevant information through the life cycle of the road infrastructure.

Collection of traffic management data and information per use case was discussed in the Chapter 5 Relevant information in NRA responsibility subchapter 5.3, where means of data provisioning such as Probe Vehicle Data (PVD), mobile network aggregated mobility data, crowdsourced data as well as roadside units and sensors data such as induction loops, traffic signals, cameras and V2I communication were introduced. The forementioned means of data provisioning can be use case dependently required by the digital twin system to further enhance the impacts of traffic management systems and services.

Maintaining and distribution of information was partly discussed in the Chapter 4 NRA roles in digital twins subchapter 4.3 and Chapter 5.3, where the different roles in the ecosystem were discussed, and mainly the traffic managers' responsibilities.

The forementioned also include traditional ways and best practices, currently being implemented, to collect, maintain and distribute traffic management information, for example use of open data and collaboration of the ecosystem stakeholders.

Traditional information and data management as well as life cycle also include for example data quality, security, privacy, accessibility and storage. While data quality and accuracy as well as security and privacy are discussed more closely in the CEDR TIARA project reports (2025), the Chapter 6.3 on KPIs includes digital twin KPIs such as accuracy, adaptability, scalability and data integration capabilities that can help to monitor and evaluate the compatibility of the information on digital twins.

Traffic management information digital representation use cases introduced in the study, presented below in Table 9, include dynamic or real-time traffic information of common operational picture for traffic management, signal control, hard shoulder running and partly electronic or digital traffic rules and regulation. More static information is included in the electronic traffic rules of access control and UVAR. Although some static information is also included, the dynamic nature of the information differs for example from the building and planning as well as asset management and maintenance information presented in the previous two chapters. Dynamic information or data (for example traffic jam condition) can have a much shorter lifecycle and higher requirement of timeliness compared to the static information of planning and building a road.

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Table 9 Traffic Management digital representation use cases.

Traffic Management digital representation use case
Common operational picture for traffic management (network level use case)
- Traffic jam conditions and end of queue
- Surface condition monitoring
- Tunnel closure and management
- Road works
- Safety related incidents and incident management
- Incident detection
- Event management
Electronic/Digital traffic rules/regulations
- General traffic regulations
- Speed limits
- Access Control / UVAR
Signal control
Hard shoulder running

Based on the previous analysis, the review in Table 10 was done to compare how traffic management information in a digital representation could differ from the information in traditional traffic management systems. The information type and use of information have been analysed and adapted from the previous sections and chapters.

Table 10 Review with exemplary comparison of traditional traffic management systems and digital twins information type and use of information. (from this report and Soni et al. 2025 as well as Wu et al. 2025)

Information type and use of information	Traditional Traffic Management Systems	Digital representations and twins
Life cycle	Operational traffic information of e.g. road works	Full life cycle of for example road infrastructure related traffic management information, e.g. road works
Data exchange	Dissemination of information or data collection, e.g. from the infrastructure such as induction loops.	Digital twin with bidirectional data exchange between the model and the real-world object that is being modelled.
Real-time information	Periodic or timely updates of the data and patch of data sets.	Real-time data for example from sensors and roadside units.
Predictive analytics and simulations	Monitoring and alerts in the Traffic Management Systems.	Use of simulation models, predictive analytics and forecasts, e.g. of traffic events and flow.
Data integration between systems	Traffic Management Center systems with data resource integrations.	Higher level of integration with BIM models, data platforms in different ecosystems with sensor data.
Models and visualisation	2D with point location information	3D model with different data layers

The collection of traffic information in such a way that it is compatible with digital twins, when analysing Table 10, should include considerations of the use case in question, the information type, and the use of information. For example, real-time data with high data flow and high requirements of data accuracy for the predictive model or simulation can set requirements for the data collection process.

Maintenance and distribution of information for digital twin or representation compatibility can include the following topics, which are partly universal for data management and governance, but are here evaluated as being highly important for a digital twin system which integrates different information and systems with possible high-rate bidirectional data exchange, a situation where interoperability, accessibility of information and reliability will ease the process and further provide more effective use of information in the models and impact on services. The following topics also partly overlap collection, maintenance and distribution of information:

- Regulation
- Standardisation, specifications and profiles
- Security and privacy
- National, European and international collaboration
- Proof of concepts and pilots

Regulation

European Union council adopted a new revised framework for the deployment of Intelligent Transport Systems (ITS) (2023/2661) in 2023. The framework directive supports coordinated use of Intelligent Transport Systems (ITS) across the Union Member States borders. According to the ITS Directive the Commission may adopt delegated acts. The following delegated acts include traffic information as presented in the study use cases and provide regulation on information requirements (Kotilainen & Kulmala 2025):

- 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).

The 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 set by Member State (Delegated Regulation 2022/670, Delegated Regulation (EU) No 886/2013). More about European ITS regulation and data accuracy responsibility can be found for example in Kotilainen & Kulmala (2025). Accessibility, exchange and re-use of data includes standardised data formats, which are further described in the next section.

Standard, specifications and profiles

Standardisation of ISO TC204 and CEN TC278 Intelligent Transport Systems that highly relates to European and international standards in traffic management is presented in the Figure 3 below by Evensen (2025). Many of the use cases link to these standards, such as C-ITS, road traffic data (DATEX II) and ITS spatial data.

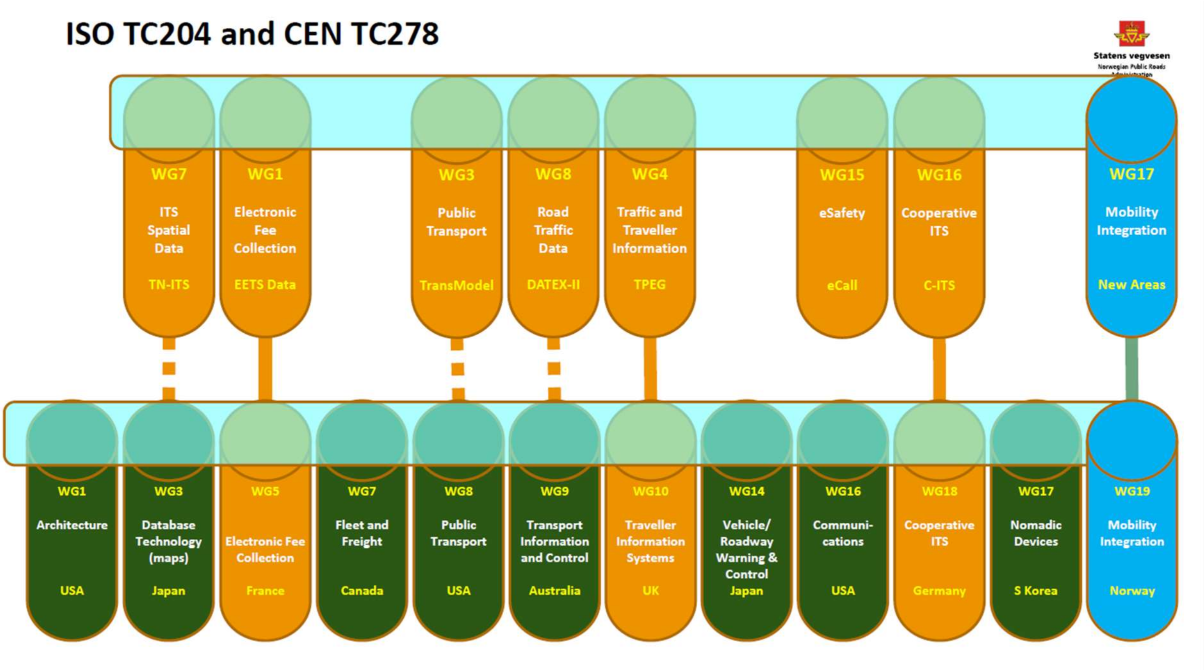

Figure 3 ISO TC204 and CEN TC278 Intelligent Transport Systems standardisation. (Evensen 2025)

The European legislation referred above mentions to accessibility, exchange and re-use of data with standardised data formats of DATEX II (EN 16157, CEN/TS 16157), INSPIRE specification and TN-ITS (CEN/TS17268). TN-ITS standards include mainly static road data and attributes, which are not discussed in here due to the scope of dynamic use cases in this study.

DATEX II (EN 16157, CEN/TS 16157)[3] standard was mentioned already above. Being the primary European standard for exchanging real-time traffic information, used in operational traffic management, is a key standard when collecting, maintaining and distributing data related to digital twins. DATEX II supports location referencing such as OpenLR standard. INSPIRE Directive is a framework for Infrastructure for Spatial Information in Europe to achieve harmonised geospatial data in Europe (INSPIRE).

Cooperative Intelligent Transport Systems (C-ITS) can also have a crucial role when exchanging data for digital twins. C-ITS is a subset of standards for Intelligent Transport Systems (ITS). C-ITS services exchange trusted and secured data between vehicles, roadside infrastructure, control and services centres in the cloud, and other road users. European framework for trusted and secure C-ITS communication, using Public Key Infrastructure (PKI), is the European Union (EU) C-ITS Security Credential Management System (EU CCMS). In Europe, C-Roads Platform, established by European road operators who work together with the industry, have developed specifications for C-ITS. For example, traffic light and signal control services are relevant to C-ITS services. (Cooperative, connected and automated mobility, C-Roads Platform)

METR ISO standardisation has been reviewed in the DROIDS project deliverable 3.4 by Soni et al. (2025) who state that “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”.

[3] DATEX II. https://datex2.eu/

Security and privacy

If not all at least most of the road operator traffic management services and data can be and should be shared with the ecosystem actors to gain benefits for road safety and flow as well as reduce emissions, to give few examples. At the same time traffic management systems and data need to be protected from cyber-attacks to prevent any disruptions that could lead to negative consequences for road safety. Mitigation techniques have been developed, for example reinforcement learning by Agarwal et al. (2022), to prevent incidents. These risks and mitigation measures also apply to digital representations and twins applied to benefit traffic management.

In addition of direct attacks to traffic management systems, there also need to be a risk assessment in place to evaluate road operator data and services that could cause risk and damage to road users, organisations, authorities or even to the member state. For example, some sensitive data could contain attributes that cause risk for road user privacy or national defence. These need to be identified, removed or mitigated in collaboration with the authorities and organisations involved.

Security and privacy are discussed more closely in the CEDR TIARA (2025) project results. Although the results are mainly for C-ITS, security includes topic of trust and privacy also applies to wider use of information. Real-time traffic information can include location data which makes it personal data and its usage in digital twins need to be monitored and measures taken to avoid data privacy issues.

National, European and international collaboration

Public and private collaboration will be one of the main priorities to develop digital twin systems and information that are compatible. This applies especially for a newly developed digital twins which currently lack experience on traffic information implementations.

Examples of such collaboration in Europe include Data for Road Safety[4], C-Roads Platform, NAPCORE, TISA and many other. Data quality and accuracy are also mentioned in here since it should be developed in collaboration, for example the TISA 5-Star rating (TISA 2024).

C-Roads Platform, which has bene established in collaboration with the European road operators for C-ITS harmonisation and cooperates with the industry, has a Working Group 5 Digital Transport Infrastructure that has a focus on the infrastructure needs for a digital infrastructure as a whole, including Traffic Management as well as HD maps. C-Roads has also created specifications for harmonised data sharing via Interchange Nodes. (C-Roads Platform 2025)

5GAA (The 5G Automotive Association) has also given recommendations for a path towards a fully digitalised road operations management. These recommendations include data availability as prerequisite for successful implementation: infrastructure owner-operators and mobility service providers in the public sector (e.g. bus operators) need to make traffic-related digital twin information available via public interfaces. (5GAA 2024)

Proof of concepts and pilots

Similarly, as mentioned in the collaboration above, proof of concepts and pilots are important especially for newly developed digital twins, such as for any other new technology or services developed in complex environment, which currently lack experience on traffic information implementations, requires testing. Only through implementations can experience and solutions be created.

Experiences and best practices from road operators – questionnaire results

[4] Data for Road Safety. https://www.dataforroadsafety.eu/

Questionnaire send to road operators, or national road authorities in Europe, answers mainly concentrated to infrastructure digital representations and twins, i.e. building and planning as well as asset management and maintenance, with digital models and shadows.

Still, according to the feedback, the answers discussed early testing, development ongoing of digital twin functionalities, organisation strategy development and upcoming technology of digital twins with future expectations. Benefits have been found on cost savings and better quality, although keeping in mind the type of use being more on static data. The mentioned feedback could indicate more testing coming with traffic information as well in future, when the infrastructure models have been built.

At the same time traffic managers and traffic management services by road operators are developing common real-time operational picture together with the stakeholders, which is part of the cooperative traffic management.

Conclusions

The best practices to collect, maintain and distribute traffic management information in such a way that it is compatible with digital twins included following latest European regulation, standards, specifications & profiles as well as security and privacy requirements. National, European and international collaboration together with proof of concepts and pilots of digital representations and twins are recommended.

Common real-time operation picture with the stakeholders and cooperative traffic management was discussed in the questionnaire results. Similarly, shared world model views on operational traffic management for example seen important for automated vehicles and local dynamic maps are partly created through C-ITS collective perception services, for example on intersections. HD maps are one example of building common maps between public and private stakeholders. Common real-time operational picture is required by the cooperative, connected and automated mobility services, which is crucial part of the TM 2.0 concept that reflects digital shadows and digital twins (TM2.0 2015). Similarly, more data sources through ecosystems such as Data for Road Safety, or data exchange through neutral servers and Interchange Nodes, can offer better operational picture. For example, information about roadworks location and status from multiple sources can benefit the data quality and further the end user.

Each selected practice and implementation should always consider the use case in question, for example road works information may include road infrastructure data with full life cycle of information while electronic and digital traffic rules as well as regulations being more static. The previously mentioned example already itself includes exceptions, for example the UVAR (Urban Vehicle Access Regulation) information which can include dynamic access control.

7.4 Information provision to external services

Data Governance Framework: Establish a framework for data ownership, access, and sharing, including data security and privacy protocols. Define roles and responsibilities for data management across the asset lifecycle, from planning through operation.

For Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness (DOVA) services there are no best practises provided as this concept has not been applied yet. However, it is anticipated that a combination of an accurate HD map and externally sourced information made available to CAVs through the DOVA principle results in better driving performance which should lead to safer, smoother, more efficient and more comfortable rides with less negative impact on the environment and liveability.

One example related to the road work zone is that externally sourced information about a work zone, provided by road operators or their contractors can help extend the digital horizon of a

CAV and therefor improve its behaviour by making it more anticipatory. Without this information, as is currently common in AV deployments in the US and China, the ADS will drive the vehicle until it detects a workzone and then tries to merge onto a lane not obstructed be the workzone. This tends to be a more difficult manoeuvre compared to a merge carried out earlier by a human operated vehicle where the driver had anticipated the situation.

It is also expected that accurate HD maps combined with externally sourced information (provided by road operators and other possible stakeholders) can contribute to a shared world model for CAVs which is comparable to a common operational picture where traffic managers have a “shared world view” and can act on that. It is important for CAVs to base their decision making on the context they are in and this should contain the assumption that they have a fairly accurate understanding of how the other vehicles, automated or not, will behave.

8 Guidelines for NRAs

8.1 Scope

According to the DROIDS workplan, the purpose of the guidelines is to provide recommendations on how to collect, maintain and distribute the information in such a way that it is compatible with digital representations i.e. models, shadows and twins. This was to be primarily based on best practices of CEDR members and other stakeholders. During the course of DROIDS, it became apparent that such best practices are very limited and deal mainly with digital models created in BIM and AIM deployments. Thereby, the guidelines are also building on lessons learnt in data and information system and service deployments as well as the DROIDS activities.

These guidelines should be treated as a first draft, which needs to evolve along with future developments. Joint monitoring activities by road authorities and operators are needed in the following years including coordinated sharing of experiences and best practices.

The guidelines are structured according to the main aspects of digital representation development, deployment, use and maintenance:

- Identify road operator roles by use case
- Utilise regulations and standards
- Maintain trust
- Exchange data with ecosystem stakeholders
- Operate, evaluate and maintain

8.2 Identify road operator roles by use case

It is obvious that the digital representation use cases differ from one another depending on not only the data types but also the roles of the various stakeholders. In addition, the CEDR member road authorities may have a number of different roles depending on their objectives and tasks set by the national governments. This means that a national road authority can have one or several of the roles of:

- road operator
- traffic manager
- (road) transport authority
- information service provider

All national road authorities have the role of the road operator, and many the roles of traffic manager as well. Some also have the role of information service provider and the transport authority. Naturally, the national road authority has to consider all of its roles in the development, deployment, operation, maintenance and use of digital representations.

We recommend that the national road authorities check the stakeholder roles by use case mapped in Annex 1 as a starting point when contemplating their role in a specific use case.

When in doubt about the urgency of a specific use case and its level (digital model vs. shadow vs. twin) it can be useful to be first active only studying the feasibility of the digital representation and passive in the other phases of digital representation development. When the digital representation use case is clearly expected to bring tangible benefit to the core processes of the national road authority, the roles should be as active as possible.

8.3 Utilise regulations and standards

In order to reap full benefits from the digital representations, these representations should provide seamless interoperability to the stakeholders utilising them, providing data into them and acquiring or extracting data from them.

This means that the national road authorities should take care to ensure that the digital representations developed, deployed and operated by or for them comply to the international (or at least European) regulations, standards, and standard profiles including OTLs (Object Type Libraries) already existing or under preparation. Such have been described in the earlier chapters (especially chapter 7) of this report.

It would also be useful if a (perhaps voluntary) European partnership or other stakeholder(s) would develop and maintain a set of specifications on how to develop, deploy, operate and maintain interoperable digital representations in the road transport domain.

8.4 Maintain trust

In order for any stakeholder utilising the digital representations contributed to or provided by national road authorities to actually use them in their daily operations, trust in the digital representations is essential. No stakeholder will use data that they can not trust in any operations that carry economic or legal liabilities. For this reason, trust is essential also for the digital representations.

For maintenance of trust, the conclusions of DROIDS WP4 provide guidance for the national road authorities. Guidance is also provided by the TIARA project (Kotilainen & Kulmala 2025), where special emphasis is laid on data accuracy and quality in connection with C-ITS services. The data quality requirements naturally depend on the digital representation use case in question. For most traffic related digital shadows, the EU EIP data quality requirements for safety-related and real-time traffic information (Kulmala et al., 2019) on the “enhanced” level apply. TIARA (Kotilainen & Kulmala 2025) stresses the importance of accompanying the data (i.e. the digital representation) with an explicit statement of the quality of the data utilising the standard quality indicators.

Trust is not only related to the accuracy or other quality of the data itself but also to the continued availability of it. Thereby, commitment to maintain the availability of the digital representation for a specific period of time (e.g. 5 years) is essential for the users of the digital representation to incorporate it in their daily processes.

8.5 Exchange data with ecosystem stakeholders

Today it is very rare that the national road authorities would themselves provide the data in the digital representations that they contribute to. In many cases, the data is provided, perhaps as a side-product, by stakeholders working as contractors for the road authorities. These contractors can plan or build roads (data for BIM), maintain them (AIM) or manage traffic for them, etc. In such cases, the obligations for data provision and exchange can easily and also should always be included in the contracts and already in the procurement documents.

In many cases, data for the digital representations can also be acquired from third-party service providers. By nature, third-party data is already there, so no national road authority needs to invest in collection of data, even though investments may be needed to process it in a format that serves the authority’s needs. The road authority may be the “secondary” user of data, or a user among a larger group of different users. This gives potential to improve data cost-efficiency compared to traditional data collection methods by national road authorities. Another benefit is typically high network coverage, as the data collection is mobile (e.g. vehicles, mobile phones) rather than point-location. In addition, third-party data may provide the road authority with new insights to their core business problems that have not yet been seen as data was not visible (PRESORT 2025).

Some ecosystems such as Waze (2025) or Data for Road Safety (2025) provide platforms for data exchange where access to ecosystem data is permitted in return for own data provision to the ecosystem as long as specific rules for data use are complied to.

In most cases, data can be purchased from the third-party service providers. The CEDR PRESORT project studied the use of third-party data and provided a set of recommendations concerning market research, procurement methods, exclusion and selection criteria, award criteria, acceptance testing, quality control, licensing, immaterial rights, use of options, etc. (PRESORT 2025)

PRESORT stressed that the procurement of data is highly dependent on the properties of the data to be acquired. Therefore, the contract terms and procurement process should always be founded on the actual properties of the data to be acquired. This will vary on the digital representation use case.

8.6 Operate, evaluate and maintain

While developing and deploying a digital representation can be cumbersome and require a lot of resources, also the operation and maintenance of it requires a lot of attention and possibly also resources. However, clever planning of the digital representation operation with automated data feeds in case of changes in the physical counterpart of the representation may drastically reduce the resources needed in the mid- to long term.

Many use cases require constant supervision of a human operator, at least in a stand-by role, as surprising unrecurring incidents that have not been anticipated in the automated processes need swift and adequate reactions, thus calling for human intervention .

In any case, regular monitoring and evaluation of the technical performance of the digital representation is recommendable. This facilitates quick detection of failures and anomalies in the digital representations. Regular quality control is very important to ensure user trust. Carefully selected Key Performance Indicators (KPIs) which include ITS and digital representation/twin KPIs help to evaluate the system(s) efficiency and operational impact as well as benefits to road users. KPIs related to safety, efficiency, mobility, energy, accuracy, adaptability, costs, scalability and data were identified in the study.

It is also useful to evaluate user satisfaction and benefit. This can be accomplished by short surveys, efficient feedback channels, or separate studies.

9 Conclusions and next steps

The research results included the following five guidelines for the road operators on how to collect, maintain and distribute the information in such a way that it is compatible with digital representations i.e. models, shadows and twins:

1. Identify road operator roles by use case
2. Utilise regulations and standards, as much as possible
3. Maintain trust
4. Exchange data with ecosystem stakeholders
5. Operate, evaluate and maintain

The research questions (RQ) of the study, which are answered below in this chapter and introduced in the chapter 1 Introduction, were recognized to require input from the following earlier DROIDS Deliverables (D) which are included and referred in this conclusions analysis:

- D2.1 State of the Art of digital twins for road infrastructure (RQ1, RQ10)
- D3.2 Information maintenance and availability (RQ6)
- D3.3 BIM representation for full life cycle of road infrastructure (RQ2, RQ3, RQ10)
- D3.4 Digital twin use cases – Digital transport regulations, opening new roads, automated lane level navigation (RQ4)

(RQ1) What role the NRAs should take in the larger ecosystem of digital twins for road infrastructures, and how they should fulfil this role?

The Table 11 below presents a summary of the NRA roles, or road operator roles (public and private), in the larger ecosystem of digital twins for road infrastructure. The original digital representation role tables in Annex 1 and role descriptions in Chapter 4 ‘NRA roles in digital twins’ include nineteen stakeholder roles in life cycle of road infrastructure digital representations, therefore it should be noted that the road operator role will evolve in collaboration with the ecosystem stakeholders depending on the use case and its requirements.

Analysis of the road operator roles in the Table 11 indicates the road operators have an active role in many of the use cases life cycle stages. Natural active roles in digital representation full life cycle for road operators is in their core business of road maintenance and asset management as well as in use of the models in road planning and building. Use cases where private industry provides products and services, such as HD maps, signal control and probe vehicle data, road operator may have a more passive role, depending on the national implementation and business models with the industry.

Table 11 Summary of the road operator roles in digital representations use cases for road infrastructure. A means active (actually carrying out the task or commissioning it), P when more passive. ( ) means that the role is valid in some European countries only. A/P refers to possible Active or Passive role, 'DM' refers to Digital Model, 'own' refers to possible responsibility to developing their own digital representation.

Road operator roles	**Life cycle of road infrastructure digital model/shadow/twin**			
Use Case	**Development**	**Operation**	**Maintenance**	**Use**
Road planning and building (model)	A	A	A	A
Road maintenance (shadow)	A	A	A	A
Winter maintenance (shadow)	A	A	A	A
Asset management (model)	A	A	A	A
Common operational picture for traffic management (network level use case)				
➢ **Traffic jam conditions and end of queue (shadow)**	P	P	P	A
➢ **Surface condition monitoring (shadow)**	A - own	A - own	A - own	A
➢ **Tunnel closure and management (shadow)**	P/A - own	P/A - own	P/A - own	A
➢ **Road works (shadow)**	A - own	A - own	A - own	A
➢ **Safety related incidents and incident management** (model)	A/P	A/P	A/P	A
➢ **Incident detection (shadow)**	A/P	A/P	A/P	A
➢ **Event management (model)**	(A)	(A)	A	A
Electronic/Digital traffic rules/regulations				
➢ **General traffic regulations (model)**	P/A		A	A
➢ **Speed limits (shadow)**			A	A
➢ **Access Control / UVAR (shadow)**	A (road tolls etc)	A (road tolls)	A (road tolls)	A
Signal control (shadow / twin)	A/P	A/P	P	A
Hard shoulder running (shadow / twin)	A/P	A/P	P	A
Automated traffic enforcement (shadow)	P/A	P/A	P/A	P/A
HD Map (shadow / model)	A (DM) - own	A (DM) - own	A (DM) - own	A
Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness (shadow)			P/A	A

(RQ2) What kind of digital representations (what kind of digital twins) should be maintained by NRAs? What will be the requirements for model-based AIM?

Road operator priorities for digital representations, “estimated likelihood of use case deployment by 2030 by at least three Member States”, that were drafted by the DROIDS project were reviewed by the road operators. The results are summarised in the Table 12 below. Road operators top three priorities were evaluated being asset management (digital model), speed limits of electronic/digital traffic rules/regulations (digital shadow) and road works (digital model). Digital models and digital shadows were estimated of being very likely for the use cases deployment by 2030 by at least three Member States.

Table 12 Road operators estimated likelihood of use case deployment by 2030 by at least three Member States. Results from the DROIDS project workshop and feedback of road operators.

Priority		Estimated likelihood of use case deployment by 2030 by at least three Member States?		
	Use case	Unlikely	Likely	Very Likely
	Common operational picture for traffic management (network level use case)			
	- Traffic jam conditions and end of queue	DT	DS	
	- Surface condition monitoring	DT		DS
9	- Tunnel closure and management	DT	DS	
3	- Road works	DT	DS	DM (static RW data)
9	- Safety related incidents and incident management	DT and DS (all stakeholders)		DM
4	- Incident detection	DT		DS

	- Event management	DT	DS (large events)	DM
8	Road maintenance	DT		DS
11	Winter maintenance	DT		DS
1	Asset management	DT	DS (high-risk assets)	DM
11	Road planning and building	DT (smart construction)	DS (smart construction)	DM
	Electronic/Digital traffic rules/regulations			
6	- General traffic regulations	DT	DS (dynamic)	DM
2	- Speed limits		DT (dynamic)	DS
4	- Access Control / UVAR		DT (dynamic)	DS
	Automated traffic enforcement		DS	DM
	Signal control		DT (dynamic)	DS
11	Hard shoulder running		DT	DS
11	HD Map	DT		DS
6	Cooperative Connected and Automated Mobility (CCAM) – Distributed ODD attribute value awareness		DT	DS

Planning and building: During the planning and building phase, BIM digital representations are crucial as they represent various attributes of the built infrastructure. The BIM information after the completion of the project represents a digital model of the as-built infrastructure. The BIM information is crucial for the NRAs to maintain since BIM models can be transitioned to asset information models (AIM). Furthermore, BIM information can also be potentially reused in HD maps for Automated Vehicles. This aspect is explored in detail within use case 1 in DROIDS deliverable D3.4.

Asset management and maintenance: Asset information models (AIM) are relevant for the road operators during asset management phase. The asset information models pull the relevant information from as-built BIM digital representation from design and construction phase. As AIM is updated continuously during asset management, it represents a digital model of the physical road infrastructure and can form a strong basis for creating a digital twin. DROIDS deliverable D3.3 explored the potential of using AIM for digital twin creation.

Traffic management and information provision to external services digital representations were concluded to be in early stage of development as the workshop, questionnaire and literature review results during the study provided only limited insight on the best practices. Nevertheless, it was concluded that since traffic managers and traffic management services by NRAs and road operators are developing common real-time operational picture together with the stakeholders and they have an active role and ownership with these digital representations (see previous RQ1 Table 11), they also have a high likelihood of ownership and being maintained by road operators.

(RQ3) Will they need to extend the level of geometric and topological complexity for this data in order to prepare for model-based AIM and connected/automated driving?

The level of geometric and topological complexity from BIM and AIM models is usually sufficient for basic operations such as construction and maintenance of the infrastructure. However, for advanced applications such as creating a digital twin for connected/automated driving, the level of detail in such models is not sufficient. For applications in connected and automated driving, High-Definition (HD) maps offer more precise and accurate models. DROIDS deliverable D3.4 discusses HD maps in detail and investigates the possibility of reusing BIM/AIM information. (Soni et al. 2025)

The road operators must focus on standardising the information by adopting ISO 19650 and implementing an object type library from early phases of the project. By following standardised approach, the information stored in digital representations would be interoperable with variety of other applications.

The study's Annex 1 includes the Asset management use case digital model questionnaire results on life cycle of road infrastructure. The results indicate an active role for road operator on full life cycle. Contractors and private industry have been evaluated of having an active role in maintenance and usage of the digital model.

(RQ4) How much responsibility should NRAs take for establishing and maintaining base data sets supporting automated driving such as High-Definition (HD) Maps, compared to the role of commercial Map Providers?

A data set is a collection of data. Base data sets are here defined as digital map and sensor data sets that can support automated driving. Static and dynamic data sets priorities for the OEMs and service providers have been for example studied in CEDR funded projects results of Kulmala et al. (2022), where wide range of roadway, digital infrastructure, environmental and operational datasets were considered priority. Many of the road operators core business and operational services already provide these base datasets: these datasets are concluded below with specific attention to the 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. 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.

DROIDS deliverable D3.4 investigated how BIM/AIM information can be reused for HD maps creation. Discussions with HD map providers indicated that it might be possible to make connections of HD maps with AIM/BIM systems given the quality of information is good, standardised and validated. Today, it is a bit early for road operators to take responsibility in managing the information for HD maps. The road operators should prioritise standardisation of their BIM process by implementing ISO 19650 and information by creating object type libraries. High maturity road operators who already have standardised OTL in place should pilot the usefulness of BIM and AIM information within HD maps in cooperation with HD map providers. At an early stage, road operators can focus on making sure that the information related to assets such as GIS information is organised, updated, and complete.

NRAs have not been developing high quality level HD maps, at least known to this study and not with the level of detail what the industry implements for automated driving systems requirements. It is questionable whether the HD maps would be NRAs core business especially when considering OEMs and service providers having vehicle fleets with substantial data collection capabilities to further enhance the HD maps and having a business case to use the map for example on automated driving.

The study's Annex 1 includes the HD maps use case digital shadow/model questionnaire results on life cycle of road infrastructure. The results indicate an active role for road operator on full life cycle with possible ownership of the model map. Digital map providers, map data service providers and vehicle fleet operators were equally identified having an active role in full life cycle of the HD map use case.

Traffic management and information provision to external services perspective to automated driving includes the following below Table 11 (chapter 5) use cases data sources and information attributes in traffic management which were considered relevant and being often in road operator responsibility.

Table 13 Summary of traffic management related data sources and attributes that are often in road operator responsibility.

Traffic management Digital representation use case	**Relevant data sources and information attributes often in road operator responsibility**
Common operational picture for traffic management (network level use case)	
- Traffic jam conditions and end of queue	Sources: Roadside units, sensors and ITS Attributes: speed, flow, time, occupancy, density, location, queue length, duration
- Surface condition monitoring	Sources: Roadside units, sensors, ITS, road weather stations Attributes: friction, temperature, humidity, location(s), maintenance activities
- Tunnel closure and management	Sources: ITS, roadside units, sensors, cameras Attributes: air quality and pressure, visibility, airflow, temperature, vehicle speeds, weather data
- Road works	Sources: NRA databases of road works information, trailers, maintenance vehicles Attributes: type of road work, location, lane or lanes impacted, validity time
- Safety related incidents and incident management	Sources: Roadside cameras and roadside units/ITS Attributes: location, type of incident, status, severity, duration, affected area/road/lane
- Incident detection	Sources: Roadside cameras and roadside units/ITS Attributes: Incident location, lane(s), type, status, duration, detour(s)

- Event management	Sources: event data Attributes: type, location, timing, affected roads, transport service changes, traffic management plan
Electronic/Digital traffic rules/regulations	
- General traffic regulations	Sources: electronic traffic regulation databases, road traffic signs that machine readable, traffic signals Attributes: user, vehicle, road, activities, environment, happenings, interactions
- Speed limits	Sources: electronic traffic regulation databases, road traffic signs that machine readable Attributes: speed limit, location, duration in distance
- Access Control / UVAR	Sources: electronic traffic regulation databases, road traffic signs that machine readable, traffic signals Attributes: location, validity, description, issuing authority, reason, regulation, status
Signal control	Sources: traffic signal and control Attributes: traffic signal, signal head, controller, communication devices, detection system, signal type
Hard shoulder running	Sources: NRAs static physical infrastructure databases and dynamic data databases of HSR Attributes: location, length, vehicle restrictions, status and availability, validity and open/closure time

(RQ5) What services and data is expected to be shared from NRAs?

Services and data that are typical and core business for NRA or road operator and their operational services and common operational picture should be shared with the ecosystem. These services and data can provide benefits for example on traffic safety and flow as well as reducing emissions. Important part of the benefits comes from OEMs and service providers who build their services by utilising the road operator data and services. The research question 4 above listed the data sources and sets which are commonly in road operator responsibility. Many of these mentioned data sources and information relate to services that the NRA offer, such as generally traffic management, incident management and tunnel closure and management. These core services and data are still also expected for digital representation use case.

Depending on the ambition and available budget and capacity that NRAs have, additional services and data that may benefit new services outside of the current NRA's scope and responsibility could be expected to be shared. For instance, certain ODD attribute values that can augment CCAM services fall in that category.

There were also exceptions identified on services and data sharing, i.e. all data and services should not be shared. For example, data that has been bought from third-party service providers and data that is under ecosystem agreement, such as Data for Road Safety ecosystem, are outside of sharing scope.

Furthermore, there also needs to be ensured that the data that is shared does not cause harm or damage. The damage can be for example security or privacy related issue. Target of the damage can be road user, public or private organisation, national authority or member state. Therefore, risk analysis is needed to evaluate any privacy, security or other risks that the data and services provided by the NRAs could include. Data privacy, security, legal ethical issues are discussed further in the CEDR funded TIARA project (2025).

(RQ6) How do these different standards and specifications serve the future digital operator role of NRAs?

Standards provide services and data common technical solutions, interoperability, scalability and reduce cost risk, to mention few benefits, across European member states borders (Leiren Boag 2025). For example, sharing of safety related traffic information or electronic traffic rules for human and automated driving system-controlled vehicles requires collaboration between public and private partners. Standards ensure a common approach and safeguard joint digital representation implementations, i.e. future proof solutions and services.

Several standards such as the following were referred in the chapter 7 of the study.

Building and planning

- ISO 19650 as the framework for information management and exchange throughout the project lifecycle
- IFC-5 and CEDR 2018 OTL
- BIM standard ISO 7817-1

Traffic Management standards and specifications were provided widely in the European regulation under the ITS Directive framework and its delegated acts, i.e. DATEX II, INSPIRE and TN-ITS. C-ITS standards have been as a basis in the C-Roads specifications. All of these serve the dynamic and static traffic management digital representations and twin in future development.

- ISO TC204 and CEN TC278 Intelligent Transport Systems
- DATEX II (EN 16157, CEN/TS 16157)
- INSPIRE specification
- TN-ITS (CEN/TS17268)
- C-Roads Platform European C-ITS specifications

(RQ10) How should the information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in maintenance of the physical infrastructure?

The RQ1 provided a summary of the road operator and stakeholders roles in digital representations use cases for road infrastructure. The different estimated active and passive roles of the stakeholders in each use case provides a view on the information maintenance throughout the life cycle.

DROIDS deliverable D3.3 discusses the maintenance of information throughout the whole lifecycle of road infrastructure. The BIM information from design and construction phase can transition into asset information model which can be used by the road operators for asset management. However, to enable such integration, road operators must adopt common standards which will allow interoperability between different information systems.

To improve information management and exchange throughout the project's lifecycle, it is essential to adopt ISO 19650 as the framework. This standard provides a structured approach for managing crucial project data and ensures consistency across all stages.

Another important aspect is developing or refining existing Building Information Modeling (BIM) standards and guidelines, which will specify the requirements for data exchange, level of detail, and format compliance. Using formats like Industry Foundation Classes (IFC) and openBIM standards will facilitate seamless communication and integration.

Creating or using a comprehensive Object Type Library (OTL) is also vital. This library defines the properties and attributes of each asset type, ensuring consistency and interoperability across various projects and organizations.

Fostering active collaboration and communication between internal stakeholders, such as BIM and Asset Information Management (AIM) departments, is crucial for mutual understanding of requirements and capabilities. Additionally, engaging with external stakeholders, including contractors, design and engineering firms, consultants, and technology providers, helps identify information requirements and ensures the needs of all parties are met.

Road operators should also focus on data governance models to understand the responsibilities behind information management. The data governance is further discussed in DROIDS deliverable 5.2.

Road operator should also pay attention to the information that is a Key Performance Indicator for the service.

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Annex 1 Digital representation role tables

Digital model/shadow/twin use case: **Road planning and building – digital model**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority				
Land use authority (e.g. city, region)	**A/P**		**P**	**A**
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**A**	**A**	**A**	**A**
Traffic manager				**(A/P)**
Road infrastructure planning contractor	**A**	**P**	**A**	**A**
Road infrastructure building contractor	**A**	**A/P**	**A**	**A**
Road works or maintenance contractor	**A**	**P**	**A**	**A**
Traffic information service provider				
Meteorological service provider				**P**
Communication infrastructure provider				
Digital map provider				**P**
Vehicle fleet operator				
Vehicle manufacturer				
Automated Driving Systems (ADS) provider	**A/P**		**A/P**	**A/P**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant				**P**

Digital model/shadow/twin use case: **Asset management – digital model**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	P	P	P	A
Communication authority				
Land use authority (e.g. city, region)	A	A	A	A
Law enforcement				A
Rescue service provider				A
Road operator	A	A	A	A
Traffic manager				A
Road infrastructure planning contractor				A
Road infrastructure building contractor			A	A
Road works or maintenance contractor			A	A
Traffic information service provider				A
Meteorological service provider	(A)		A	A
Communication infrastructure provider				A
Digital map provider			A	A
Vehicle fleet operator	P	P/A	A	A
Vehicle manufacturer				A
Automated Driving Systems (ADS) provider	P		A	A
Research / academic institutes	P			A
Vehicle owner/ driver/ occupant			A	A
AI developer (decision support)	A			(A)

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Digital model/shadow/twin use case: **Road maintenance – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	P	P	P	A
Communication authority				
Land use authority (e.g. city, region)				A
Law enforcement				A
Rescue service provider				A
Road operator	A	A	A	A
Traffic manager	A	A	A	A
Road infrastructure planning contractor				
Road infrastructure building contractor				A
Road works or maintenance contractor	A - own	A - own	A - own	A
Traffic information service provider				A
Meteorological service provider				
Communication infrastructure provider				A
Digital map provider				A
Vehicle fleet operator	P	P/A	A	A
Vehicle manufacturer				A
Automated Driving Systems (ADS) provider	P		A	A
Research / academic institutes	P			A
Vehicle owner/ driver/ occupant			A	A

Digital model/shadow/twin use case: **Winter maintenance – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	P	P	P	A
Communication authority				
Land use authority (e.g. city, region)				A
Law enforcement				A
Rescue service provider	P			A
Road operator	A	A	A	A
Traffic manager	A	A	A	A
Road infrastructure planning contractor				
Road infrastructure building contractor				A
Road works or maintenance contractor	A - own	A - own	A - own	A
Traffic information service provider				A
Meteorological service provider	A - own	A - own	A - own	A
Communication infrastructure provider	P/A			A
Digital map provider				A
Vehicle fleet operator	P	P/A	A	A
Vehicle manufacturer				A
Automated Driving Systems (ADS) provider	P		A	A
Research / academic institutes	P			A
Vehicle owner/ driver/ occupant			P	A

Digital model/shadow/twin use case: **Traffic jam conditions/end of queue – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**P**
Communication authority				
Land use authority (e.g. city, region)				
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**P**	**P**	**P**	**A**
Traffic manager	**A (P)**	**A (P)**	**A (P)**	**A**
Road infrastructure planning contractor				**A**
Road infrastructure building contractor				**A**
Road works or maintenance contractor				**A**
Traffic information service provider	**A - own**	**A - own**	**A - own**	**A**
Meteorological service provider				**P**
Communication infrastructure provider				**A**
Digital map provider				**A**
Vehicle fleet operator	**P**	**P/A**	**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider	**P**		**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant				**A**

Digital model/shadow/twin use case: **Pavement surface condition monitoring – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority				
Land use authority (e.g. city, region)				
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**A - own**	**A - own**	**A - own**	**A**
Traffic manager	**A**	**A**	**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				**A**
Road works or maintenance contractor	**A - own**	**A - own**	**A - own**	**A**
Traffic information service provider				**A**
Meteorological service provider	**A - own**	**A - own**	**A - own**	**A**
Communication infrastructure provider				**A**
Digital map provider			**A**	**A**
Vehicle fleet operator	**P**	**P/A**	**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider	**P**		**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant				**A**

Digital model/shadow/twin use case: **Tunnel closure and management – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority				
Land use authority (e.g. city, region)				
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**P/A - own**	**P/A - own**	**P/A - own**	**A**
Traffic manager	**A - own**	**A - own**	**A - own**	**A**
Road infrastructure planning contractor				**A**
Road infrastructure building contractor				**A**
Road works or maintenance contractor			**A**	**A**
Traffic information service provider				**A**
Meteorological service provider				**A**
Communication infrastructure provider				**A**
Digital map provider			**A**	**A**
Vehicle fleet operator			**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider			**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant				**A**

Digital model/shadow/twin use case: **Road works management – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**A/P**	**A/P**	**P**	**A**
Communication authority				
Land use authority (e.g. city, region)				
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**A - own**	**A - own**	**A - own**	**A**
Traffic manager	**A - own**	**A - own**	**A - own**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor	**A - own**	**A - own**	**A**	**A**
Road works or maintenance contractor	**A - own**	**A - own**	**A**	**A**
Traffic information service provider	**A - own**	**A - own**	**A - own**	**A**
Meteorological service provider				**A**
Communication infrastructure provider				**A**
Digital map provider			**A**	**A**
Vehicle fleet operator	**P**	**P/A - own**	**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider	**P**		**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant				**A**

Digital model/shadow/twin use case: **Incident management – digital model**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**(P)**	**(P)**	**(P)**	**A/(P)**
Communication authority				**A**
Land use authority (e.g. city, region)				**A**
Law enforcement			**A**	**A**
Rescue service provider			**A**	**A**
Road operator	**A/P**	**A/P**	**A/P**	**A**
Traffic manager	**A**	**A**	**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				**A**
Road works or maintenance contractor			**A**	**A**
Traffic information service provider			**A**	**A**
Meteorological service provider			**A**	**A**
Communication infrastructure provider				**A**
Digital map provider			**A**	**A**
Vehicle fleet operator	**P/A -own**	**P/A - own**	**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider	**P**		**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant			**A**	**A**

Digital model/shadow/twin use case: **Incident detection – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**(P)**	**(P)**	**(P)**	**A/(P)**
Communication authority				**A**
Land use authority (e.g. city, region)				**A**
Law enforcement	**P**		**A**	**A**
Rescue service provider	**A**	**A**	**A**	**A**
Road operator	**A/P**	**A/P**	**A/P**	**A**
Traffic manager	**A**	**A**	**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				**A**
Road works or maintenance contractor			**A**	**A**
Traffic information service provider	**P/A -own**	**P/A – own**	**A**	**A**
Meteorological service provider			**A**	**A**
Communication infrastructure provider				**A**
Digital map provider			**A**	**A**
Vehicle fleet operator	**P/A -own**	**P/A - own**	**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider	**P**		**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant			**A**	**A**

Digital model/shadow/twin use case: **Event management – digital model**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority				**A**
Land use authority (e.g. city, region)				**A**
Law enforcement			**A**	**A**
Rescue service provider			**A**	**A**
Road operator	**(A)**	**(A)**	**A**	**A**
Traffic manager	**A**	**A**	**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				**A**
Road works or maintenance contractor			**A**	**A**
Traffic information service provider			**A**	**A**
Meteorological service provider			**A**	**A**
Communication infrastructure provider			**A**	**A**
Digital map provider			**A**	**A**
Vehicle fleet operator	**A-own**	**A-own**	**A**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider	**P**		**A**	**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant			**A**	**A**
Event organiser / manager	**A - own**	**A-own**	**A-own**	**A**

Digital model/shadow/twin use case: **General electronic transport regulations – digital model**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**A**	**A**	**A**	**A**
Communication authority				**A**
Land use authority (e.g. city, region)			**A**	**A**
Law enforcement	**A**		**A**	**A**
Rescue service provider				**A**
Road operator	**P/A**		**A**	**A**
Traffic manager	**P/A**		**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				**A**
Road works or maintenance contractor				**A**
Traffic information service provider				**A**
Meteorological service provider				**A**
Communication infrastructure provider				**A**
Digital map provider	**A/P**		**A (possible updates)**	**A**
Vehicle fleet operator	**A**	**A/P**	**A (possible updates)**	**A**
Vehicle manufacturer	**(A)**		**A (possible updates)**	**A**
Automated Driving Systems (ADS) provider	**A**	**A/P**		**A**
Research / academic institutes	**P**		**P**	**A**
Vehicle owner/ driver/ occupant				**P**

Digital representation use case: **<u>Electronic transport regulations/speed limits – digital</u> shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	P/A	P	P/A	A
Communication authority	A			A
Land use authority (e.g. city, region)			A	A
Law enforcement			A	A
Rescue service provider			A	A
Road operator			A	A
Traffic manager	A	A	A	A
Road infrastructure planning contractor				
Road infrastructure building contractor			P(A	A
Road works or maintenance contractor			P/A	A
Traffic information service provider	P			A
Meteorological service provider				A
Communication infrastructure provider				A
Digital map provider	P		A	A
Vehicle fleet operator	P		A	A
Vehicle manufacturer	P			A
Automated Driving Systems (ADS) provider	P		A	A
Research / academic institutes				A
Vehicle owner/ driver/ occupant			A	A

Digital model/shadow/twin use case: **Electronic transport regulations/ Access control/UVAR - digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	A/P	A/P	A/P	A
Communication authority	A			A
Land use authority (e.g. city, region)	A (UVAR)	A (UVAR)	A (UVAR)	A
Law enforcement			A	A
Rescue service provider				A
Road operator	A (road tolls etc)	A (road tolls)	A (road tolls)	A
Traffic manager	A (access control)	A (access control)	A (access control)	A
Road infrastructure planning contractor				A
Road infrastructure building contractor				A
Road works or maintenance contractor				A
Traffic information service provider				A
Meteorological service provider				A
Communication infrastructure provider				A
Digital map provider	P			A
Vehicle fleet operator	P			A
Vehicle manufacturer	P			A
Automated Driving Systems (ADS) provider				A
Research / academic institutes				A
Vehicle owner/ driver/ occupant				A

Digital model/shadow/twin use case: **Signal control – digital shadow / twin**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority	**P**			
Land use authority (e.g. city, region)				
Law enforcement	**P**	**P**	**P**	**A**
Rescue service provider	**A/P**	**P**	**P**	**A**
Road operator	**A/P**	**A/P**	**P**	**A**
Traffic manager	**A**	**A**	**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				
Road works or maintenance contractor			**A**	**A**
Traffic information service provider				**A**
Meteorological service provider				
Communication infrastructure provider	**A/P**			**A**
Digital map provider				**A**
Vehicle fleet operator		**P**	**P**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider				**A**
Research / academic institutes	**P**	**P**		**A**
Vehicle owner/ driver/ occupant				**A**

Digital model/shadow/twin use case: **Hard shoulder running – digital shadow / twin**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority				
Land use authority (e.g. city, region)				
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**A/P**	**A/P**	**P**	**A**
Traffic manager	**A**	**A**	**A**	**A**
Road infrastructure planning contractor				
Road infrastructure building contractor				**A**
Road works or maintenance contractor			**A**	**A**
Traffic information service provider				**A**
Meteorological service provider				**A**
Communication infrastructure provider				**A**
Digital map provider				**A**
Vehicle fleet operator				**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider				**A**
Research / academic institutes	**P**			**A**
Vehicle owner/ driver/ occupant				**A**

Digital model/shadow/twin use case: **Automated traffic enforcement - digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	P	P	P	A
Communication authority				
Land use authority (e.g. city, region)	P/A		P/A	A
Law enforcement	A	A	A	A
Rescue service provider				A
Road operator	P/A	P/A	P/A	P/A
Traffic manager	P/A	P/A	P/A	A
Road infrastructure planning contractor				
Road infrastructure building contractor				
Road works or maintenance contractor				
Traffic information service provider				A
Meteorological service provider				
Communication infrastructure provider				A
Digital map provider				A
Vehicle fleet operator				A
Vehicle manufacturer				A
Automated Driving Systems (ADS) provider				A
Research / academic institutes				A
Vehicle owner/ driver/ occupant				A

Digital model/shadow/twin use case: **HD maps – digital shadow/model**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	**P**	**P**	**P**	**A**
Communication authority				**A**
Land use authority (e.g. city, region)	**A (DM) - own**	**A (DM) - own**	**A (DM) - own**	**A**
Law enforcement				**A**
Rescue service provider				**A**
Road operator	**A (DM) - own**	**A (DM) - own**	**A (DM) - own**	**A**
Traffic manager				**A**
Road infrastructure planning contractor				**A**
Road infrastructure building contractor				**A**
Road works or maintenance contractor				**A**
Traffic information service provider				**A**
Meteorological service provider				**A**
Communication infrastructure provider				**A**
Digital map provider	**A (DS)**	**A (DS)**	**A (DS)**	**A**
Vehicle fleet operator	**A (DS) - own**	**A (DS) - own**	**A (DS) - own**	**A**
Vehicle manufacturer				**A**
Automated Driving Systems (ADS) provider			**A (DS)**	**A**
Research / academic institutes				**A**
Vehicle owner/ driver/ occupant				**A**
Map data service provider	**A**	**A**	**A**	**A**

Digital model/shadow/twin use case: **CCAM (Distributed ODD attribute value awareness) – digital shadow**

A means active (actually carrying out the task or commissioning it), **P** when more passive. ( ) means that the role is valid in some European countries only.

	Life cycle of road infrastructure digital model/shadow/twin			
Stakeholder	**Development**	**Operation**	**Maintenance**	**Use**
Transport authority (ministry, agency)	P	P	P	A
Communication authority	P	P	P	
Land use authority (e.g. city, region)			P/A	A
Law enforcement			A	A
Rescue service provider			A	A
Road operator			P/A	A
Traffic manager	(A)	(A)	A	A
Road infrastructure planning contractor				
Road infrastructure building contractor			P/A	A
Road works or maintenance contractor			P/A	A
Traffic information service provider			A	A
Meteorological service provider			P/A	A
Communication infrastructure provider			P/A	A
Digital map provider			A	A
Vehicle fleet operator	A - own	A - own	A - own	A
Vehicle manufacturer			P/A	A
Automated Driving Systems (ADS) provider	P		A	A
Research / academic institutes	P			A
Vehicle owner/ driver/ occupant				A